PLANE GEOMETRICAL DRAWING

ROBERT HARRIS

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PLANE GEOMETRICAL DRAWING

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NOTE-BOOK

ON

PLANE GEOMETRICAL DRAWING

WITH A CHAPTER ON SCALES, AND AN INTRODUCTION
TO GRAPHIC STATICS

BY

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OF DRAWING-BOOKS FOR USE IN PUBLIC SCHOOLS"

NEW EDITION, REVISED AND ENLARGED.

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1895

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PREFACE.

THIS note-book on Practical Geometry has been written primarily to meet the requirements of students preparing for the Entrance Examinations of the Royal Military Academy at Woolwich, and the Royal Military College at Sandhurst.

It is hoped that the book may also be of use to Candidates for the Engineering College, Cooper's Hill; the Indian Public Works and Telegraph Department, the Royal Marine Light Infantry, the Art Master's Certificates of the Third Grade, Science Subject I. of the Science and Art Department, the Oxford and Cambridge Local Examinations, &c.

Solutions of problems set at Woolwich and Sandhurst are given, together with a chapter on Scales, and an introduction to Graphic Statics; with methods of applying instruments used in Military Surveying and Engineering.

It has been my object to give as much practical information on the subject of Plane Geometrical Drawing as the limits of one volume would allow.

A knowledge of Practical Geometry is the basis of all the mechanical and decorative arts; and many of the problems given will themselves suggest the application for practical purposes.

Acknowledgment must be made of the valuable assistance received from Bradley's *Elements of Geometry*, Lacroix' *Éléments de Géométrie*, Sonnet's *Géométrie Théorique et Pratique*, and other authorities, which have been consulted in the progress of the work.

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GEOMETRICAL DRAWING.

INTRODUCTORY HINTS.

NEATNESS and accuracy are essential for the working of the problems, and care should be taken to see that your instruments are in good order.

Avoid drawing unnecessary lines, and all which are drawn should be made long enough not to require subsequent prolongation.

Draw all lines from left to right, and avoid pressing against the edge of the ruler or other instrument, as it produces an uneven line.

Construction lines should be drawn as fine as you conveniently can, either continuous or dotted.

In using the compasses, press as lightly as possible, to avoid making holes in the paper.

Make all construction on as large a scale as is practicable, in order to ensure the utmost attainable accuracy.

The instruments necessary for Practical Geometry are:—

Compasses.—One large pair, having a movable leg to insert a pencil or pen for drawing circles of long radii, and one smaller pair called dividers.

Bow-pencil and Bow-pen.—For drawing circles of short radii.

Ruling pen.—For inking-in straight lines.

Six-inch ruler. — This should be carefully selected—one having decimal scales, scale of chords or protractor for measuring angles, and inches accurately marked, is the best.

Set squares.—Two—one a 45° set square, called so because two of its angles are 45° and the third angle 90°; the other a 60° set square, called so because one angle is 60°, another is 30°, and the third angle 90°. These are used for drawing lines perpendicular and parallel to each other.

DEFINITIONS.

1. A point marks position only.

2. A line has length without breadth.

3. A right or straight line is the shortest distance between two points.

4. A curved line is always changing its direction, and no part of it is straight.

5. A vertical line is upright.

6. A horizontal line is perfectly level.

7. An oblique line is neither horizontal nor vertical.

8. Parallel straight lines are two or more lines drawn in the same plane, such that if produced indefinitely either way they would never meet.

9. Parallel arcs of circles are concentric—*i.e.*, arcs of different circles having the same centre.

10. A perpendicular. When one straight line stands upon another straight line and makes the adjacent angles equal, these angles are called right angles; and the line standing upon the other is said to be perpendicular to it.

11. A plane rectilineal angle is the inclination of two straight lines to each other, which meet in a point.

12. There are three kinds of angles—a right angle, containing 90° (see definition 10); an obtuse angle, which is greater or blunter than a right angle; an acute angle, which is less or sharper than a right angle.

When an angle has opened out until the arms are in the same straight line, it may then be considered as an angle equal to two right angles, or 180°. Such an angle is sometimes called a straight angle.

13. Triangles are plane figures bounded by three straight lines, and have therefore three angles. Any one side may be called the base.

The sum of the angles of any triangle equals two right angles, or 180°.

14. An equilateral triangle has three equal sides, and therefore three equal angles. Each angle contains 60°.

15. An isosceles triangle has two equal sides, and therefore two equal angles. An equilateral triangle is also isosceles.

16. A scalene triangle has three unequal sides and three unequal angles.

17. A right-angled triangle has one angle equal to a right angle. The side opposite the right angle is called the hypotenuse. A right-angled triangle may be isosceles.

18. An acute-angled triangle has three acute angles.

19. The apex or vertex of a triangle is the corner opposite the base.

20. The altitude of a triangle is a line drawn from the apex at right angles to the base or base produced.

21. A rectilineal figure is a figure formed by three or more straight lines.

22. Quadrilaterals are figures formed by four straight lines and have therefore four angles. The sum of the angles of quadrilaterals is four right angles, or 360°.

23. Quadrilaterals are of six kinds—four of which are parallelograms and two trapezia.

24. Parallelograms have their opposite sides equal and parallel, and their opposite angles equal. They are a square, an oblong or rectangle, a rhombus, and a rhomboid.

25. A square has four equal sides and four equal angles. Each angle is a right angle, 90°.

26. An oblong or rectangle has its opposite sides equal and all its angles right angles.

27. A rhombus has four sides equal and its opposite angles equal. (It has two angles obtuse and two angles acute.)

28. A rhomboid has its opposite sides equal and its opposite angles equal. (It has two angles obtuse and two angles acute.)

29. There are two kinds of trapezia—a trapezium and a trapezoid.

30. A trapezium has no two of its sides parallel nor opposite sides equal, but may have two of its opposite angles equal.

31. A trapezoid has two only of its sides parallel, and may have adjacent angles equal.

32. A diagonal of a quadrilateral or any rectilineal figure is a straight line joining two of its opposite angles.

33. A diameter of a rectilineal figure having an even number

of sides is a straight line drawn through the centre, parallel to or at right angles to two of its sides.

34. A polygon is a figure having more than four sides and more than four angles. It is also called multilateral (many-sided) for a similar reason. There are two kinds—regular, having equal sides and equal angles; and irregular, having unequal sides and unequal angles.

35. A polygon with 5 sides is called a pentagon.
,, ,, 6 ,, a hexagon.
,, ,, 7 ,, a heptagon.
,, ,, 8 ,, an octagon.
,, ,, 9 ,, a nonagon.
,, ,, 10 ,, a decagon.
,, ,, 11 ,, an undecagon.
,, ,, 12 ,, a dodecagon.

A polygon may have any number of sides more than four, but for general use the above are sufficient.

36. A circle is a figure contained by a line which is called the circumference, and is such that all straight lines drawn from a certain point within it, called the centre, to the circumference are equal.

37. A radius is a straight line drawn from the centre of a circle to the circumference.

38. A diameter is a straight line drawn across the circle and terminated by the circumference, but passing through the centre.

39. A chord is any straight line drawn across the circle terminated by the circumference, but not passing through the centre.

40. An arc is a portion of the circumference of a circle.

41. A segment is a portion of a circle bounded by a chord and that part of the circumference which it cuts off.

42. A sector is a portion of a circle bounded by two radii and that part of the circumference intercepted by them.

43. The circumference of a circle subtends at the centre an angle equal to four right angles (360°). A sector containing a quarter of a circle is called a quadrant.

44. A semicircle is half a circle; it is bounded by a diameter and half the circumference. Two straight lines drawn from any point on the circumference to the ends of the diameter are at right angles to each other.

45. In a segment less than a semicircle lines drawn from any point on the arc to the ends of the chord contain an angle

greater than a right angle, and in a segment greater than a semicircle an angle smaller than a right angle.

46. A tangent is a straight line lying in the plane of the circle which meets the circumference in one point, and only one. This point is called the point of contact.

47. If a radius of a circle be continued outside the circle, the whole line is a normal to the circle—*i.e.*, a perpendicular to the circumference.

48. Similar figures are not necessarily equal in area; but are equi-angular and corresponding sides are proportional.

49. One rectilineal figure is said to be inscribed within another when each angular point of the former figure lies upon a side of the latter.

50. A right figure is inscribed within a circle when all the angles of the figure lie on the circumference of the circle.

51. A right figure is described about a circle when each side of the figure is tangential to the circle.

52. An ellipse is a figure bounded by a continuous curve, and is such that the sum of any two straight lines drawn from two fixed points within it, called the foci, and meeting together on the curve is constant—*i.e.*, always the same.

53. Tangents and normals can be drawn to an ellipse.

54. The area of a plane figure is expressed by the number of square inches or square feet, &c., its surface contains.

55. A surface has only two dimensions, length and breadth.

56. A plane surface is flat, and is called a rectilineal surface when bounded by straight lines, and curvilineal when bounded by curved lines.

57. The perimeter of a figure is the sum of its sides. Thus, the perimeter of a triangle is a line equal in length to the sum of the three sides.

58. Periphery is the measurement round curved surfaces.

59. A spiral is a curve traced out by a point which continually recedes from its initial position, and at the same time moves round it. The initial position of the point is called the pole of the spiral.

60. An involute. Suppose a perfectly flexible line to lie along a curve so as to coincide with it; if it be then gradually unwound, each point in the line will describe an involute of the curve.

PRACTICAL GEOMETRY.

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(1) To bisect a given straight line AB.

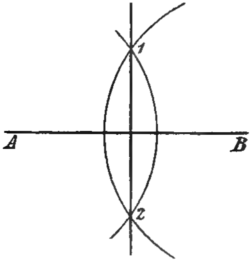


FIG. 1.

With centres A and B, and more than half the line a radius, describe arcs cutting each other in points 1 and 2. A straight line joining 1, 2 bisects AB. (10 Euc. I.)

An arc is bisected in the same manner as Problem 1.

(2) To bisect an angle ABC.

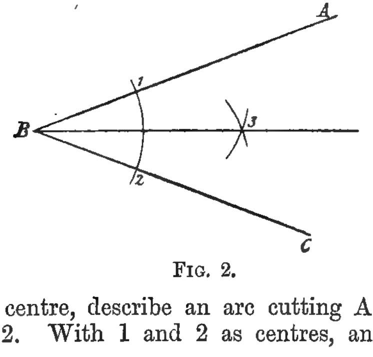


FIG. 2.

With B as centre, describe an arc cutting AB and BC in points 1 and 2. With 1 and 2 as centres, and any radius, describe arcs cutting each other in point 3. A straight line drawn through points B and 3 bisects the angle. (9 Euc. I.)

(3) To erect a perpendicular at point C, to a given straight line AB.

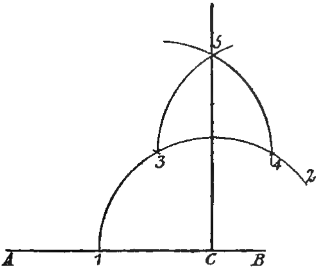


Fig. 3.

From C, with any radius, describe an arc 1, 2. From 1, with radius C1, set off on the arc 1, 2, points 3 and 4; with 3 and 4 as centres describe arcs meeting in point 5. Draw a line from C through point 5. This line is the perpendicular required. (11 Euc. I.)

(4) To draw a perpendicular to AB from a point C lying away from the line.

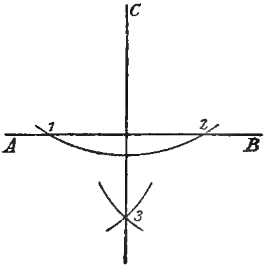


Fig. 4.

From C describe an arc cutting AB, or AB produced in points 1 and 2. With 1 and 2 as centres, and any radius, describe arcs meeting in point 3. The line C3 is perpendicular to AB.

If point C is beyond the extremity of the line AB, take any two points as centres in AB, as 1 and 2, and describe arcs through point C, intersecting below the line AB in a point 3. A line drawn through points C and 3 will be perpendicular to AB. (12 Euc. I.)

(5) To draw a line parallel to AB, and at a given distance from it.

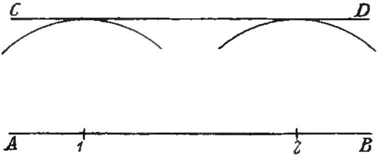


FIG. 5.

Take any two points 1 and 2 in AB as centres, and describe arcs with a radius equal to the given distance. The line CD drawn tangential to the arcs is parallel to AB, and at the required distance from it.

(6) To draw a line parallel to AB, and passing through a given point C.

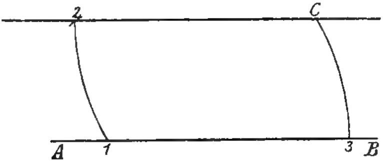


FIG. 6.

With C as centre, and any radius, describe an arc 1, 2. With 1 as centre, and the same radius, describe an arc C3. Make the arc 1, 2 equal to the arc C3. The line drawn from C through point 2 is the parallel required. (31 Euc. I.)

(7) To draw a line from a given point C, to meet a given straight line AB, and making a given angle X with AB.

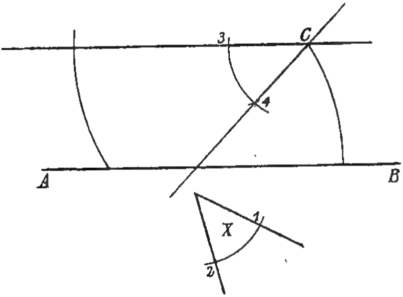


Fig. 7.

By the last problem, draw a line through C parallel to AB. With the corner of the given angle X as centre, describe an arc 1, 2; and with C as centre, and the same radius, describe the arc 3, 4. Measure the length of the arc 1, 2 in the angle X, and set off from 3 to 4 on the arc 3, 4. The line from C drawn through point 4 makes the required angle with AB. (29 Euc. I.)

(8) Method of dividing a line AB into a prime number of equal parts.

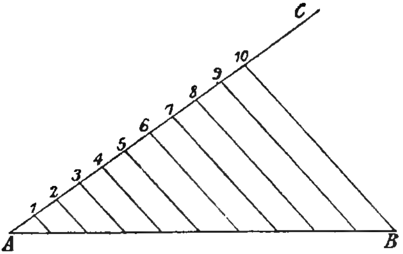


Fig. 8.

Draw the line AC, making any convenient angle with AB. and set off the required number of equal parts, as 1, 2, 3, &c.,

Join the last division (10) and B. Draw lines from 9, 8, &c., parallel to 10B. AB is divided into the required number of equal parts. (Set squares may be used.) (2 Euc. VI.)

(9) To divide a given line AB into two segments which shall have to each other a given numerical ratio of 7 : 5.

Divide the line AB into 7 + 5 parts, by Problem 8. The 7th or 5th point of division will obviously divide the line in the given ratio.

(10) To divide a space contained between two parallel lines AB and CD into any number of equal parts, by means of lines parallel to AB,—in this case 10 equal parts.

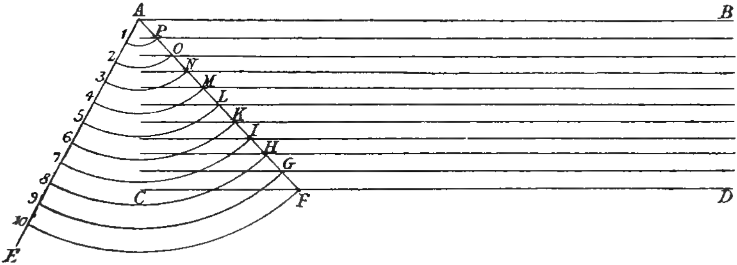


FIG. 9.

Draw AE, making any convenient angle with AB, and set off on this line the required number of equal parts, which may be any size—viz., 1 to 10. With centre A, and radius A10, describe an arc cutting CD in F. Join AF. From A describe arcs with radii A9, A8, &c., cutting AF in points G – – – – – – – – P. Through these points draw lines parallel to AB. (Set squares may be used.)

(11) To bisect the angle contained by two converging straight lines AB and CD.

Draw any line 1, 2 across the converging lines, and make the angle M equal to the angle N. Bisect the angle 3, 2, 1 by line 2, 4. Bisect the line 2, 4 by line EF. EF bisects the angle between AB and CD.

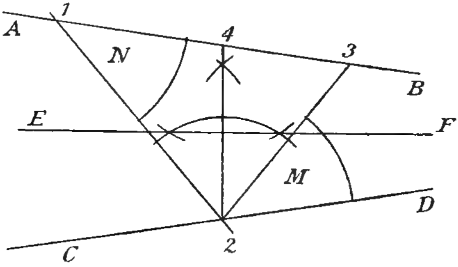


FIG. 10.

(12) From a point A taken anywhere between two converging straight lines BC and DE, to draw

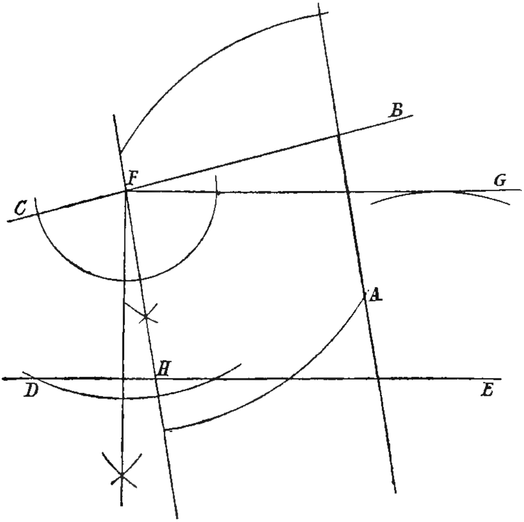


FIG. 11.

a line making equal angles with the two given straight lines.

From any point F in one of the converging lines, as BC, draw a line FG, parallel to DE. Bisect the angle CFG by a line meeting DE in H. A line drawn from A parallel to FH is the line required.

(13) To draw a line through a given point E that would pass through the point in which two lines AB and CD would meet if produced.

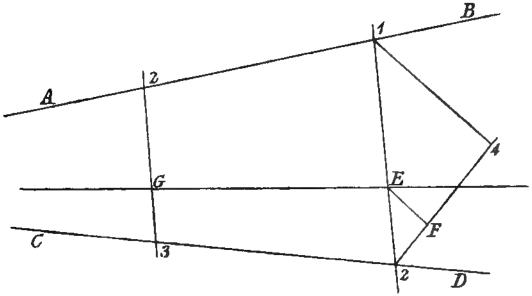


FIG. 12.

Draw any straight line 1, 2 through point E, and line 2, 3 parallel to 1, 2. From point 2 draw a line 2, 4, making any angle with 1, 2 and equal in length to 2, 3. Join 4, 1. From E draw EF parallel to 1, 4. Set off 3 G, equal to 2 F. From E draw a line through G. The line 2, 3 is divided in the same proportion as the line 1, 2.

(14) To construct angles of a given number of degrees, as 15°, 30°, 45°, 60°, 90°, 120°, and 135°.

At A draw a line AC at right angles to AB, and trisect the right angle. Thus, from C mark off CE with radius AC, and from F set off FD with radius AC. The angle CAB = 90°, DAB = 60°, EAB = 30°. Bisect 30° we obtain 15°. Bisect

90°, 45° is obtained; 90° + 30° = 120°, and 90° + 45° = 135°.

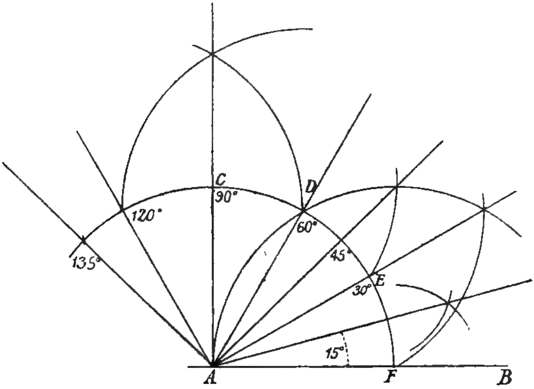


Fig. 13.

By further sub-dividing, angles containing other numbers of degrees may be constructed.

(15) To construct a scalene triangle the length of the sides AB, 3″, BC, 2½″, CA, 2″, being given.

Draw a line AB, 3″ long, for the base. With B as centre, and radius BC, describe an arc; with A as centre, and radius CA, describe another arc. The two arcs intersect in point C. Join the points AC CB. (22 Euc. I.)

(16) To construct an equilateral triangle, the base AB being given.

With A and B as centres, and radius AB, describe arcs intersecting each other in C. Join AC CB. (1 Euc. I.)

(17) Given any triangle ABC to find the altitude.

With the apex C as centre describe an arc cutting AB, the base, or the base produced in points 1 and 2. With 1 and 2 as centres describe arcs intersecting in point 3. Join C3. This line meets the base or base produced in point D. CD is the altitude.

(18) To construct an equilateral triangle, the altitude CD being given.

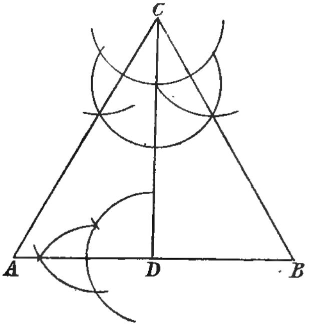


FIG. 14.

From C draw lines making 30° with CD. Through D draw a line at right angles to CD. The lines from C and the line through D meet each other in points A and B. ABC is the equilateral triangle required.

(19) To construct a triangle, the altitude CD and the two angles at the base, A and B being given.

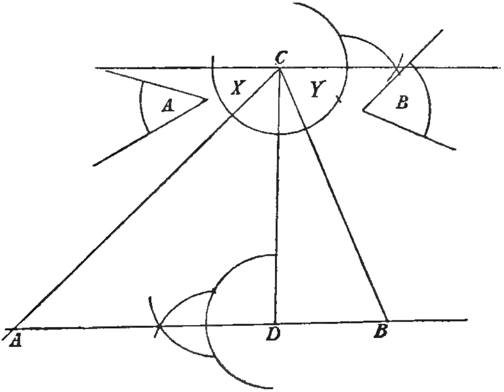


FIG. 15.

Through C and D draw lines at right angles to CD. From

C draw lines CA and CB, making angles X and Y equal to the given angles A and B. ABC is the required triangle.

(20) To construct an isosceles triangle, the base AB, 1″ long, and the altitude CD, $2\frac{1}{4}''$ long, being given.

Draw the base AB and bisect it by a line at right angles in point D. From D set off the altitude $2\frac{1}{4}''$ to point C. Join CA CB. ABC is the triangle required.

(21) Given one side AC, and one of the angles N, at the base of an isosceles triangle, to construct it.

Draw the side AC. From A draw a line AD, making an angle with AC equal to N. With C as centre, and radius CA, describe an arc intersecting the line AD in point B. Join CB. ABC is the triangle required.

(22) To construct an isosceles triangle, the base AC, and the angle at the apex B, being given.

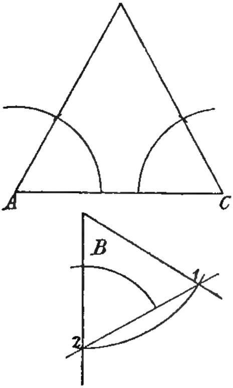


Fig. 16.

With centre B, and any radius, describe an arc 1, 2. Join 1, 2 by a straight line, and make the angles at A and C equal to the angle B, 2, 1. The angle at the apex is equal to the given angle.

(23) To find the centre point in any triangle equidistant from the sides.

Bisect two angles of the triangle by lines meeting in point O. Point O is equidistant from the sides of the triangle, and is a centre of the triangle.

(24) To find a point equidistant from the corners of a triangle.

Bisect two of the sides by lines meeting in point O. Point O is equidistant from the corners of the triangle and is a centre of the triangle.

(25) To draw a triangle having a given perimeter AB, and similar to a given triangle CDE.

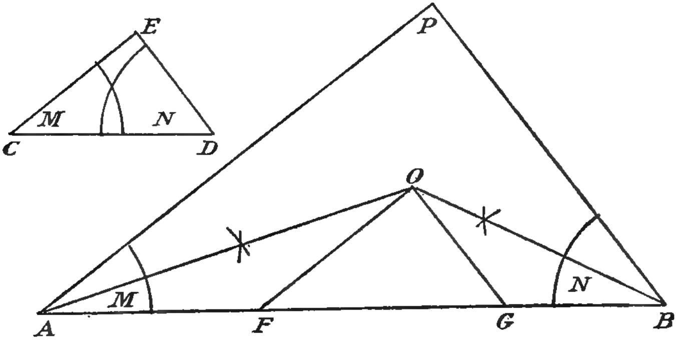


FIG. 17.

On AB draw a triangle similar to the given triangle CDE by making the angles M and N equal to M and N. Find the centre O of the triangle ABP. From O draw lines OF OG parallel to AP BP. FGO is the triangle required.

(26) Within a triangle to place a similar triangle, having a base of a given length, also a common centre.

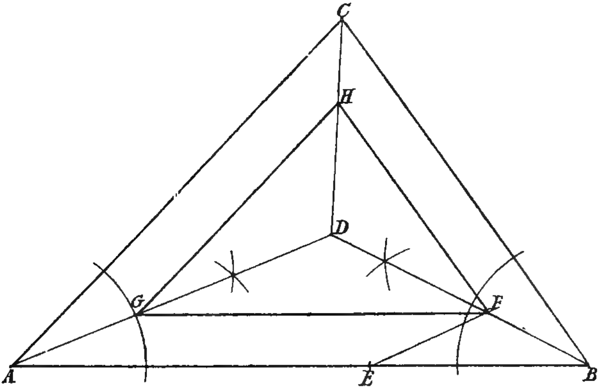


FIG. 18.

Find the centre D of the triangle; join D and the corners of the triangle; set off AE on AB equal to the given base. From E draw a line parallel to AD, meeting DB in point F. Draw FG and FH parallel to AB and BC. Join GH. FGH is the triangle required.

Note.—By this method triangles may be placed about triangles, parallelograms within or about parallelograms, polygons within or about polygons.

(27) To draw a right-angled triangle, two sides AB, $2\frac{1}{2}''$, and BC, $1''$, being given.

Bisect AB in O and describe a semicircle on AB. From B set off on the semicircle BC. Join CA. The triangle ABC is the right-angled triangle required.

(28) The hypotenuse AB, $3''$, of a right-angled triangle is given, and is twice the length of the base, construct the triangle.

Draw the hypotenuse AB and bisect in O, describe a semicircle on AB. From B set off on the semicircle a length equal to BO in point C. Join CA CB. ABC is the triangle required.

(29) To draw a right-angled triangle, the hypotenuse and the perpendicular let fall upon it from the opposite angle being given.

On a line AB equal to the hypotenuse describe a semicircle. Parallel to the hypotenuse, at a distance from it equal to the perpendicular, draw a line meeting the semicircle in C ABC is the triangle required.

(30) Within a triangle to inscribe one similar to another given triangle.

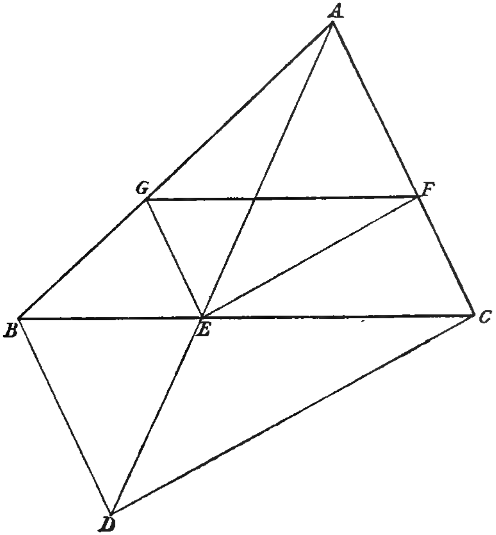


Fig. 19.

On BC construct a triangle BCD similar to the second given triangle. Join DA by a line meeting BC in E. From E draw lines EF and EG parallel to CD and BD. Join FG. EFG is the triangle required.

(31) To construct a triangle having a given perimeter AB, and its sides in a given ratio, as 2 : 3 : 4.

Draw the perimeter AB and divide it into 9 equal-parts, $2+3+4=9$. From A to the 4th division will be one side, from the 4th to the 7th division a second side, from the 7th division to B the third side of the triangle. The problem resolves itself into this: Given the three sides of a triangle, to construct it. (22 Euc. I.)

(32) To draw a triangle having a given angle, the base and the sum of the remaining sides.

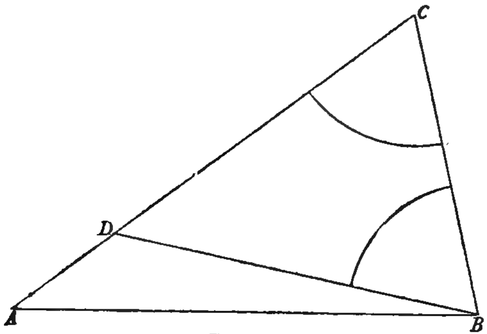


FIG. 20.

Draw a triangle ABC, making the angle BAC equal to the given angle and the line AC equal to the sum of the remaining sides. Make the angle CBD equal to ACB. ABD is the triangle required.

(33) To draw a triangle whose perimeter is 3″ and its angles as 2 : 3 : 4.

Determine the angles of the triangle thus:

$$\frac{180 \times 2}{9} = 40^\circ \qquad \frac{180 \times 3}{9} = 60^\circ \qquad \frac{180 \times 4}{9} = 80^\circ$$

On AB as base which is equal in length to the perimeter, construct a triangle having the required angles. From C, the centre of this triangle, draw lines CD and CE parallel to the sides of the triangle. CDE is the triangle required. (29 Euc. I.)

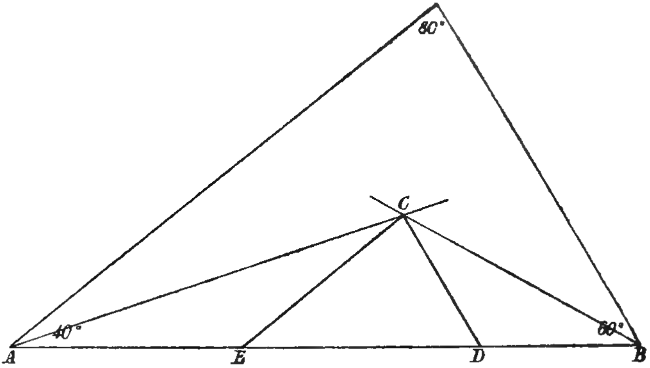


Fig. 21.

(34) To construct a triangle whose perimeter is 5″. Altitude $1\frac{1}{4}$″, and the vertical angle 45°.

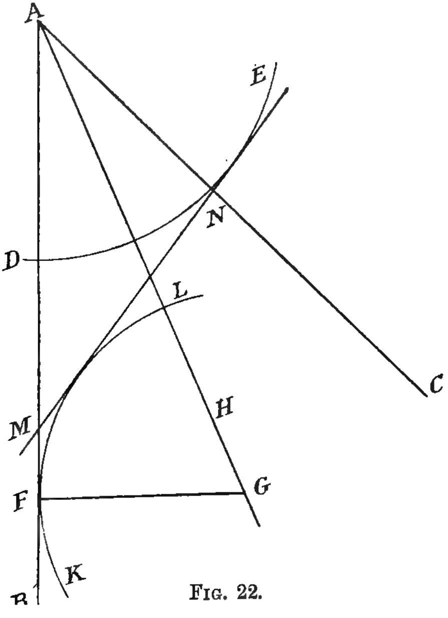


Fig. 22.

Draw lines AB, AC, making 45° with each other. With A as centre, and $1\frac{1}{4}''$ radius, describe an arc DE.

Measure on the line AB a length equal to half the perimeter as AF, draw FG at right angles to AB, and meeting the line AH, which bisects the vertical angle in point G. With G as centre, and radius GF, describe the arc KL. A line tangential to the arcs KL and DE contains the base of the required triangle; this tangent meets the lines AB and AC in points M and N. The triangle AMN is the one required.

(35) To inscribe a square within a triangle.

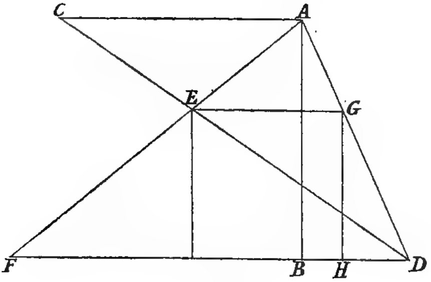


FIG. 23.

Draw AB, the altitude of the triangle; make AC equal to AB and at right angles. Join CD by a line cutting AF in point E, a corner of the required square. Draw the sides of the square parallel to the altitude and the base of the triangle respectively.

(36) To inscribe an oblong having a given side within a given triangle.

Set off AD on AB equal to the side of the oblong. Draw a line from D parallel to AC, meeting BC in point E.

Draw EF parallel to AB, and lines FH, EG perpendicular to AB. GEFH is the oblong required.

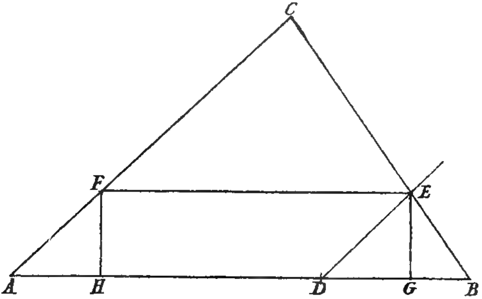


FIG. 24.

(37) One angle of a triangle is 60°, the base 1·5″, and the sum of the two sides 2·5″. Draw the triangle.

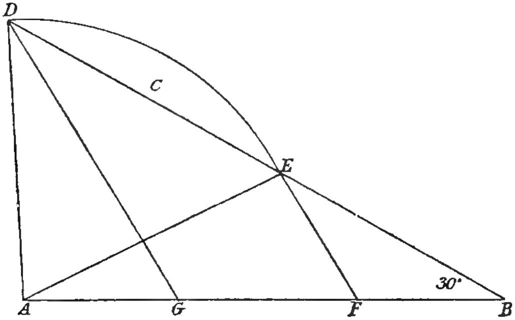


FIG. 25.

Draw a line AB equal to the sum of the sides, also a line BC making half the required angle with AB. With A as centre, and radius equal to the given base, describe an arc cutting BC in D and E. Make the angle FEB equal to the angle FBE. Draw DG parallel to EF. Both the triangles AGD and AEF fulfil the conditions.

(38) Given a circle, to draw a chord so that the angle subtended by it at the circumference of the circle may be equal to a given angle.

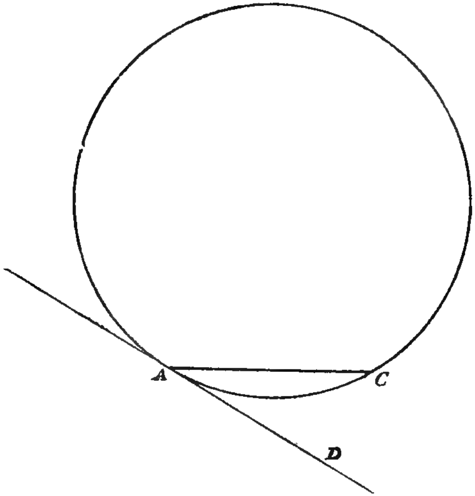


FIG. 26.

Draw a tangent from any point A in the circumference. Make the angle DAC equal to the given angle. AC is the chord required.

(39) To construct on a given line AB as a chord, an arc of a circle, which shall be capable of a given angle.

Make ABD equal to the given angle. Draw a line from B, at right angles to BD, to meet the line bisecting AB at right angles in point C, the centre of the arc required. (33 Euc. III.)

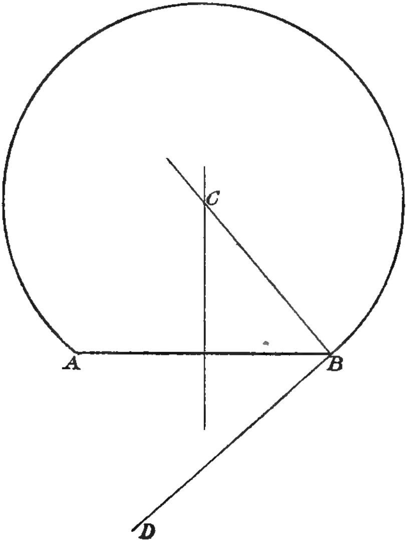


Fig. 27.

(40) To draw a triangle when the verticle angle, base, and sum of the sides are given.

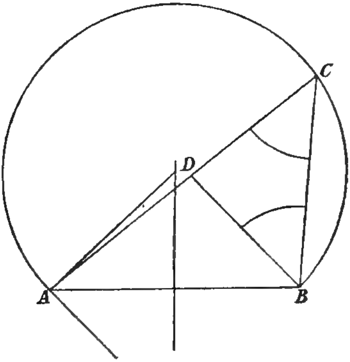


Fig. 28.

On a line AB equal to the base as a chord, draw the segment of a circle to contain half the given vertical angle. With A as centre, and radius equal to the sum of the sides of the triangle, describe an arc cutting the segment in C. Join AC and BC. Make the angle DBC equal to DCB. ABD is the triangle required.

(41) To construct a square on AB as one side.

At one end B of the given line erect a perpendicular BC. Make BC equal in length to AB. With A and C as centres, and radius equal to the given side, describe arcs meeting in point D. ABCD is the square required. (46 Euc. I.)

(42) Given the diagonal AC of a square, to construct it.

Bisect AC in O. With O as centre, and radius OA, describe a circle intersecting a line bisecting AC at right angles in points B and D. ABCD is the square required.

(43) To construct an oblong or rectangle, two adjacent sides AB and AD being given.

At A erect a perpendicular to AB equal in length to AD. With B as centre, and radius AD, describe an arc; with D as centre, and radius AB, also describe an arc: the arcs intersect in point C. ABCD is the oblong required.

(44) Given one side and a diagonal of an oblong, to construct it.

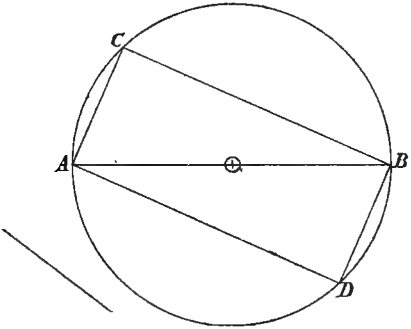


FIG. 29.

Bisect the diagonal AB in point O. With O as centre, and radius OA, describe a circle. Set off from A and B, AC and BD equal to the given side. Join AD and BC. ABCD is the oblong or rectangle required.

(45) To draw a rhombus, one of the sides AB and one of the acute angles being given.

From a point A draw two lines meeting together and containing the given angle. From A make AB and AD equal in length to each other. With B and D as centres, and radius AB, describe arcs intersecting in point C. ABCD is the rhombus required.

(46) To draw a rhombus, a diagonal EF and one of the sides GH being given.

Take points E and F as centres, and describe arcs with radius equal to GH, meeting in M and N. EMFN is the rhombus required.

(47) To draw a rhomboid when AB and EF are the lengths of two adjacent sides, and S is one of the angles.

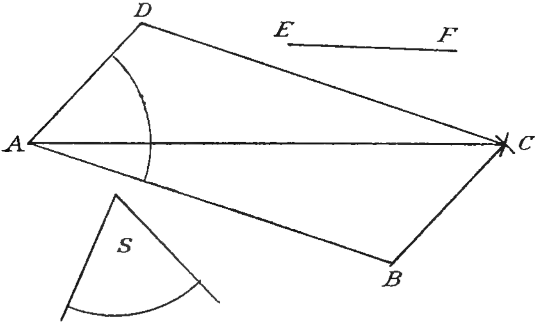


FIG. 30.

Make the angle BAD equal to S. Mark off AD equal to EF. With B as centre, and EF as radius, describe an arc; with D as centre, and radius AB, also describe an arc. The arcs intersect in point C. ABCD is the rhomboid required.

(48) To draw a rhomboid, a diagonal AC and two adjacent sides AB and AD being given. (See last figure.)

With A and C as centres, describe arcs with radius AB, above and below AC; also, with A and C as centres, and radius AD, describe arcs intersecting the first two arcs in E and F. ABCF is the rhomboid required.

(49) To construct a trapezium with pairs of equal adjacent sides, when the adjacent sides are 2″ and 1″ and the included angle 120°.

Draw two lines AB and BC making 120° with each other, and 2″ and 1″ in length respectively. Join AC. On the opposite side of AC make a triangle ADC equal to the triangle ABC. ABCD is the trapezium required.

Note.—The diagonals of a trapezium with pairs of equal adjacent sides are always at right angles to each other.

(50) To inscribe a square within a trapezium having pairs of equal adjacent sides.

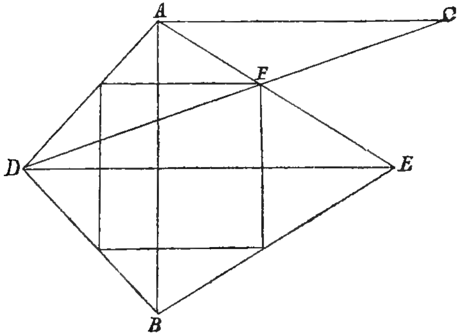


FIG. 31.

Draw the diagonal AB; make AC equal to AB and at right angles. Join CD by a line cutting AE in F, a corner of the required square. The sides of the square are drawn parallel to the diagonals.

(51) To place a rectangle within a square ABCD, the length of one side being given.

Draw the diagonals of the square AC and BD. From C on AC set off CM equal to the given length of side. Bisect CM by a line meeting CD and CB in E and F. Draw FG and EH parallel to AC. EFGH is the required oblong.

(52) To find the centre of a given circle.

Draw any two chords. Bisect the chords by lines at right angles, intersecting in point O the centre of the circle. (1 Euc. III.)

(53) To draw a tangent to a given circle or arc, at a given point of contact B.

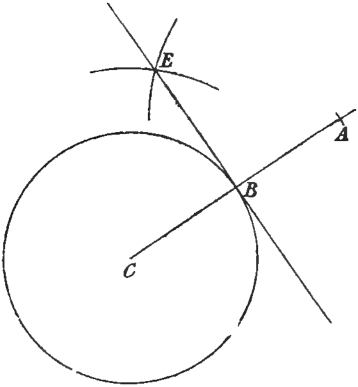


FIG. 32.

Find the centre C of the circle or arc by the last problem. From C draw the radius CB and produce it, making BA equal to CB. With A and C as centres describe arcs intersecting in E. A line drawn through E and B is the tangent to the circle. (16 Euc. III.)

Note.—The line AC is a normal to the circle.

(54) To draw a tangent to an arc, without using the centre from which the arc is described.

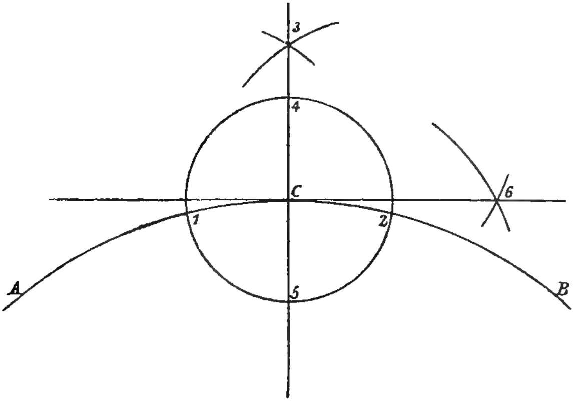


Fig. 33.

AB is the arc and C the point of contact. With C as centre, and any radius, describe a circle, cutting the arc in 1 and 2. With centres 1 and 2, and any radius, describe arcs meeting each other in point 3. Draw a line from 3 through C, cutting the circle in points 4 and 5. With 4 and 5 as centres, describe arcs meeting in point 6. A line drawn from 6 through point of contact C is the tangent required.

(55) From a point B outside a circle, to draw a line cutting the circle in two points, x and y, so that the chord xy shall be equal to a given straight line AD.

Set off the length of AD anywhere in the circle, as EF. With the centre C of the circle as centre, and radius CB, describe an arc meeting EF produced in point G. With B as centre, and radius FG, cut the circumference of the circle in

x. Draw a line from B through x, meeting the circumference in y. The chord required is xy.

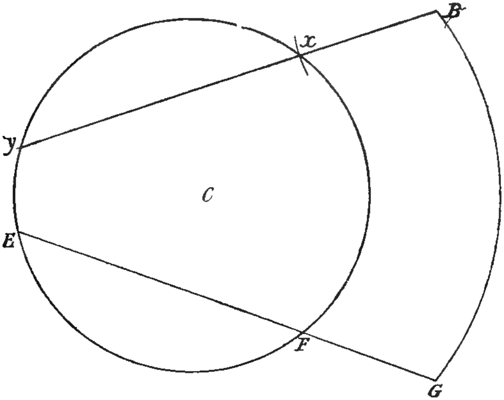


FIG. 34.

(56) Draw a straight line AB, 4″ long; trisect it at points C and D; at C erect a perpendicular CE, $\frac{3}{8}$″ long. Draw the arc of a circle to pass through AE and B without finding or making use of the centre, and determine at least six other points in the arc.

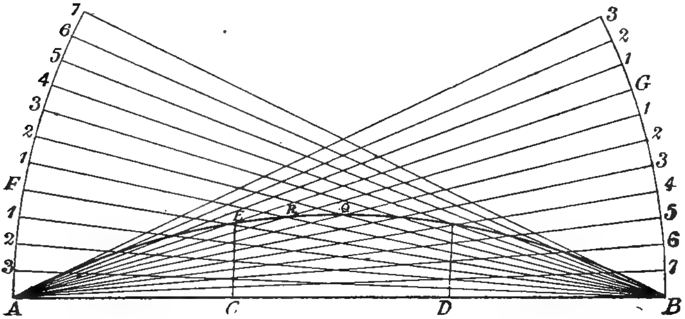


FIG. 35.

With A and B as centres, and radius AB, describe indefinite arcs. Draw lines from A and B through E, to cut the arcs in F and G. Set off from these points equal chords each way along the arcs, as 1, 2, 3, &c. Draw lines from A and B through these points of division. B1 cuts A1 in point R, in the supposed circle, and B2 cuts A2 in another point Q, &c. The problem is completed by taking the points in their proper order, and drawing the curve freehand through the points.

(57) To draw a straight line tangential to a circle, from a point outside the circumference.

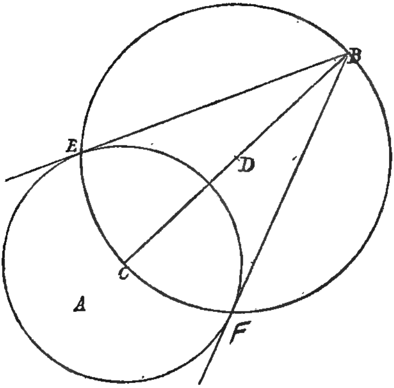


Fig. 36.

A is the circle, and B the given point. Join B and C, the centre of the circle. Bisect BC in D. On CB describe a circle, cutting the circumference in E and C. From B draw lines through the points of contact E and F. BE or BF is the tangent required.

(58) To draw a tangent to two equal circles; *a*, exterior; *b*, interior.

a. Join the centres of the circles A and B, erect perpendiculars at A and B to the line AB, meeting the circumferences of the circles in H and I. Through these points of contact draw the tangent MN.

b. Join the centres of the circles A and B. Bisect AB in C, and describe semicircles on AC and CB; these semicircles cut the circumferences of the circles in D and E. Through these points of contact draw the tangent FG.

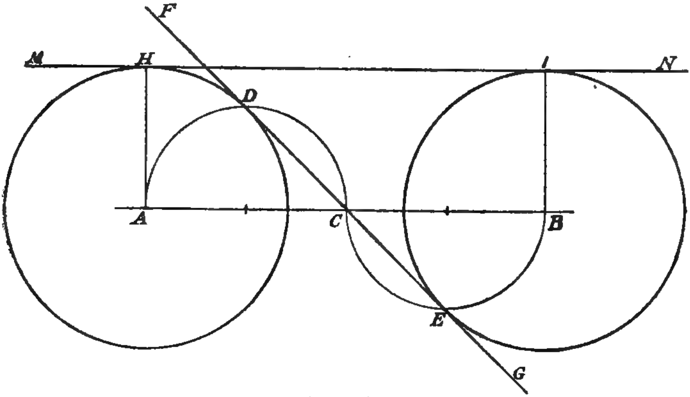


FIG. 37.

(59) To draw an exterior tangent to two unequal circles.

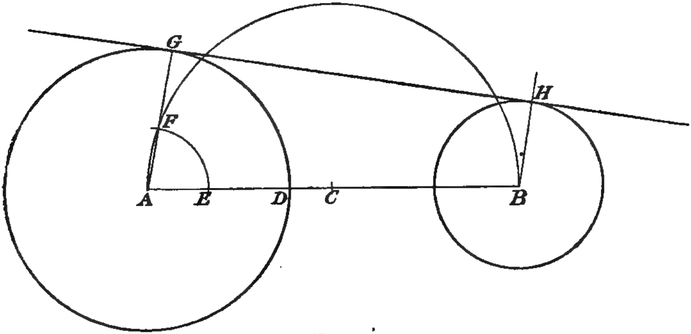


FIG. 38.

Join the centres A and B. Bisect AB in C, and describe a semicircle on AB. Set off DE equal to the radius of the circle B. Make AF equal to AE. Draw a line from A through point F on the semicircle, cutting the circumference of the circle A in G. From B draw a line parallel to AG, cutting the circumference of the circle B in H. Through G and H, the points of contact, draw the tangent required.

(60) To draw an interior tangent to two unequal circles.

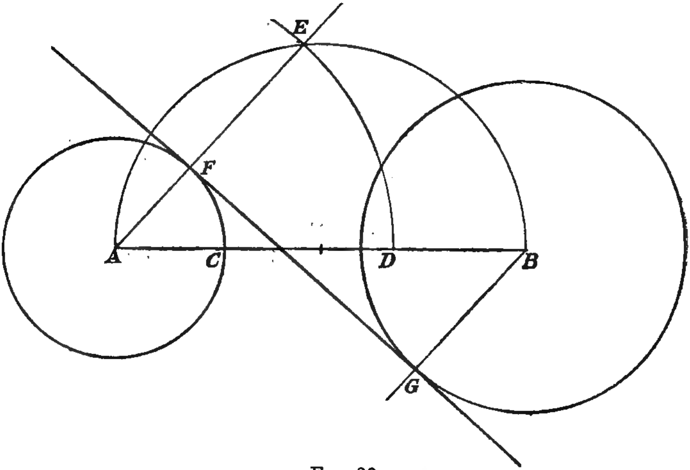


FIG. 39.

Join the centres A and B, and describe a semicircle on AB. CD equals the radius of the circle B. With A as centre, and radius AD, describe an arc, meeting the semicircle in E. Draw AE, cutting the circumference of circle A in F. From the centre of the circle B draw a line parallel to AE, meeting the circumference of circle B in G. Through F and G, the points of contact, draw the tangent required.

(61) To draw a circle of a given radius E, which shall be tangential to two converging straight lines, AB and CD.

Draw FG and HK parallel to AB and CD respectively, at distances equal to the radius E. These lines intersect in L, the centre of the required circle.

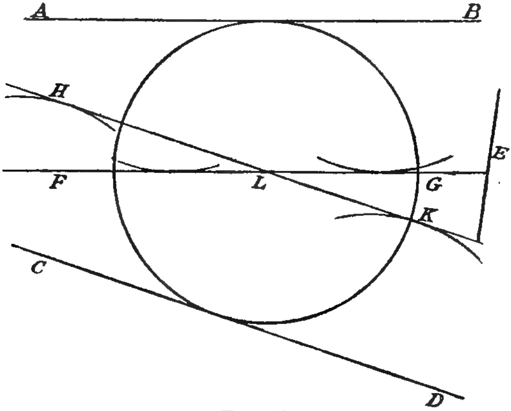


FIG. 40.

(62) Given two circles tangential to each other exter-

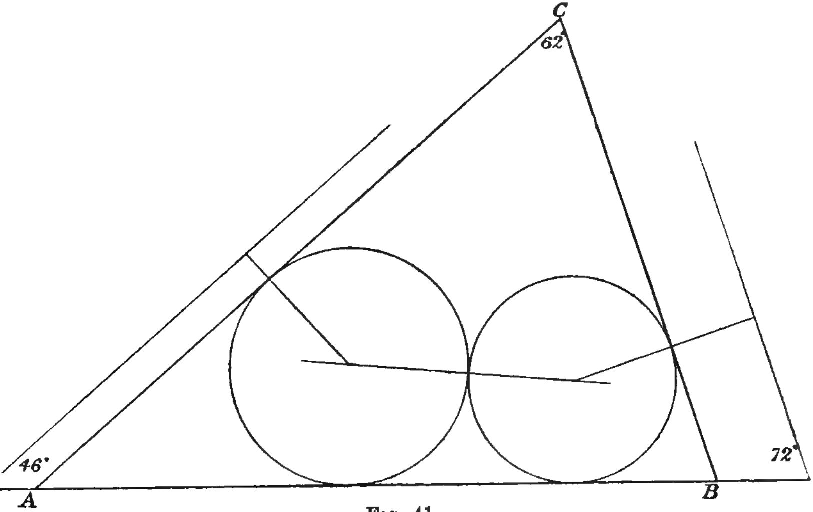


FIG. 41.

nally, to circumscribe a triangle whose angles shall be 46°, 62°, and 72°.

Draw a line AB tangential to the two circles by Problem 59. From any points in A and B draw lines making 46° and 72° with AB. Lines drawn parallel to these, each tangential to a circle, complete the triangle ABC required.

(63) To inscribe a circle within a given triangle ABC.

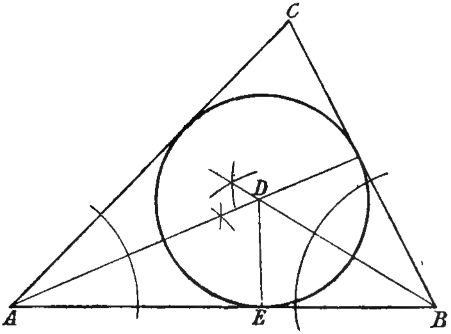


FIG. 42.

Bisect the angles BAC and CBA by lines meeting in D, the centre of the triangle. Draw DE at right angles to AB. With D as centre, and radius DE, describe the circle required. (4 Euc. IV.)

(64) To describe a circle to touch any three given straight lines.

Bisect two of the angles formed by the lines or the lines produced, and proceed as in the last problem.

(65) To draw a circle of a given radius to touch a given straight line AB, and a given circle C.

Draw FG parallel to AB, at a distance from AB equal to the given radius. Draw the line CD, and set off DE equal to the radius of the required circle. An arc described from C

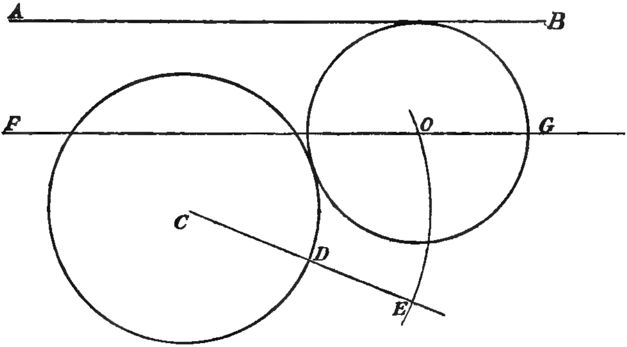


FIG. 43.

with radius CE, meets FG in point O, the centre of the required circle.

(66) To draw a circle of a given radius D to touch a given straight line AB, and to enclose a given circle C.

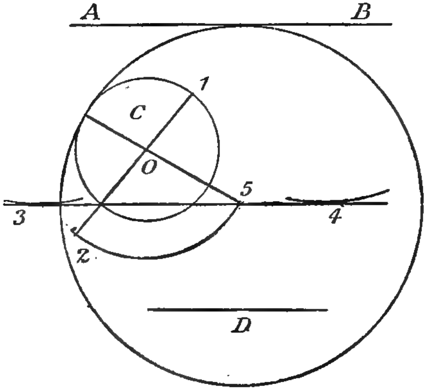


FIG. 44.

Draw any diameter across the circle C, and measure from one end of it a distance 1, 2 equal to the given radius. Draw a line 3, 4 parallel to AB, at a distance from AB equal to D. With O the centre of the circle C as centre, and radius O2, describe an arc meeting the line 3, 4 in point 5, the centre of the required circle.

(67) To draw a circle of a given radius tangential to two given circles C, C.

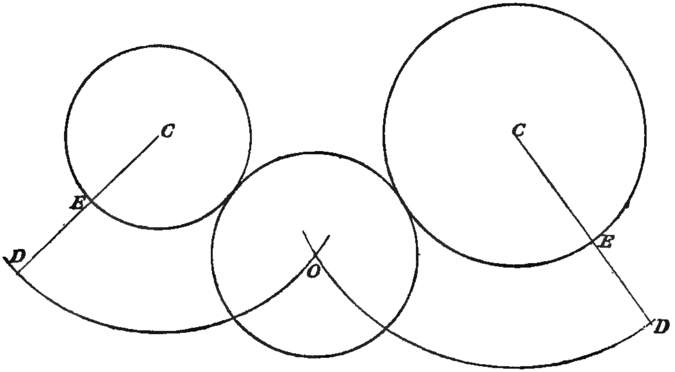


FIG. 45.

Draw the radius CE in each circle and produce them. Make ED equal to the radius of the required circle; arcs described from C and C, with radius CD, intersect in O, the centre of the required circle.

(68) To draw a circle of a given radius, tangential to and enclosing two given circles.

From any points, as A and B in the given circles, draw indefinite lines through the centres. Set off from A and B the radius of the required circle, as AE and BF. From C as centre, and radius CE, and from D, with radius DF, describe arcs intersecting in G, the centre of the required circle.

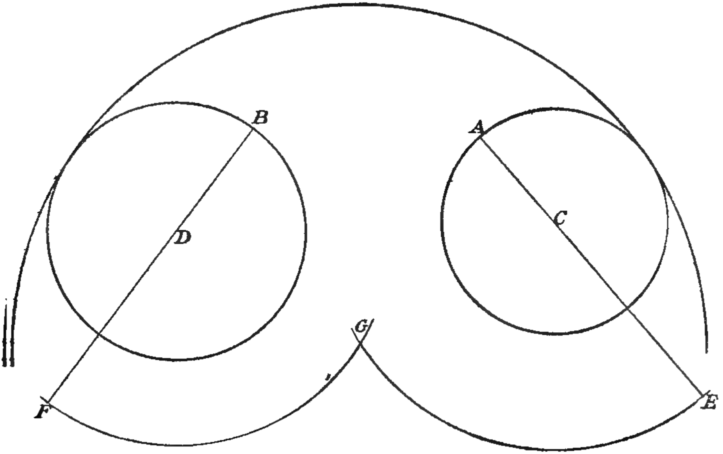


FIG. 46.

(69) To draw a circle to touch a straight line AB and a given circle C in a given point P.

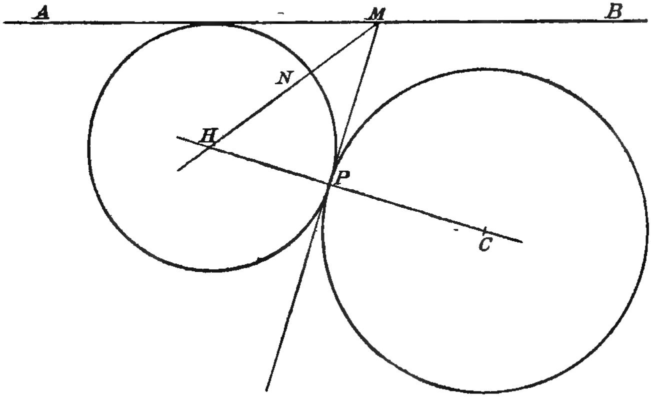


FIG. 47.

Draw the radius CP. Through P draw a tangent to the circle, meeting AB in point M. MN is drawn bisecting the angle AMP, and meeting CP produced in H, the centre of the required circle.

If a line be drawn from point M bisecting the angle BMP, and meeting PC produced, the centre of a circle is found that will enclose circle C, be tangential to it at point P, and tangential to the line AB.

(70) To draw a circle to pass through a given point P, and tangential to two given converging straight lines.

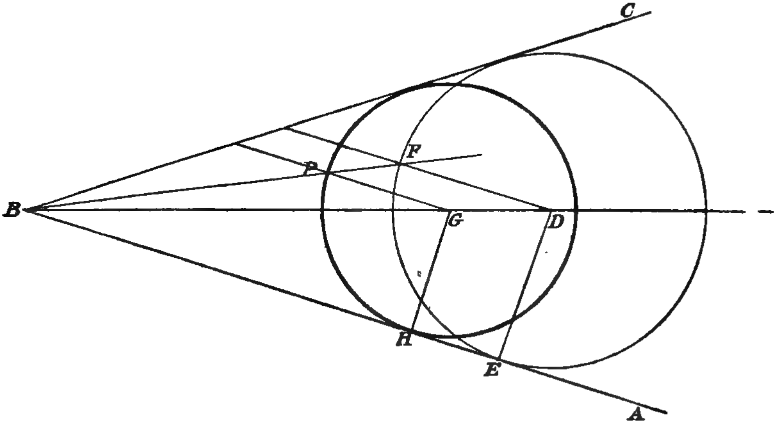


FIG. 48.

Draw BD bisecting the angle CBA. With D as centre, and radius DE, describe a circle tangential to the two converging lines. Through P draw a line PB, cutting the circumference of this circle in point F. From P draw a line parallel to DF, meeting BD in point G, the centre of the required circle; GH is the radius drawn perpendicular to AB.

(71) To draw a succession of circles to touch two straight lines and each other in succession.

The first circle C is drawn by Problem 61.

Draw the radius FG at right angles to AB, and HK at right angles to the bisecting line LF, meeting DE in point K. Make KM equal to HK, and draw MN at right angles to DE, meeting LF in N, the centre of the second circle. This construction repeated gives the centre of a third circle, and so on for others, either to the right or left of the first circle.

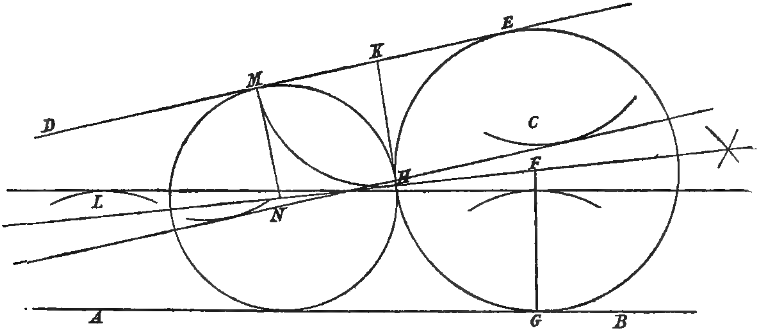


FIG. 49.

(72) To inscribe two circles having given radii A and B, within a given circle C, tangential to each other and the given circle.

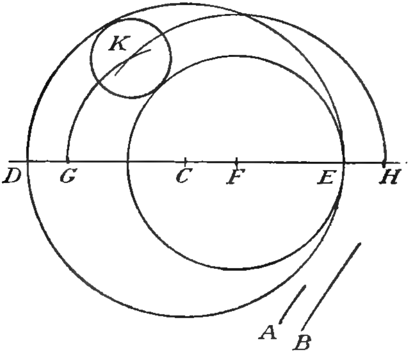


FIG. 50.

Draw a diameter DE, and produce it beyond E. From E set off EF on EC within the circle equal to A; and from F as centre, FE as radius, inscribe the first required circle. From D, with radius B, set off DG on DC within the circle; and from E, same radius, set off EH outside the circle. Then from the centre of the given circle C, with radius CG, describe an arc; and from F, with radius FH, describe another, cutting that from G in K, which is the centre, B being the radius of the second required circle.

Note.—The sum of the diameters of the inscribed circles must not be greater than the diameter of the given circle.

(73) To describe a circle to touch a given circle in a given point A, and to pass through a point B outside the circle.

Join AB, and bisect AB by a line at right angles, meeting a line drawn from A through the centre of the given circle in point C. With C as centre, and radius CA or CB, describe the circle.

(74) To draw a circle to touch a given circle C, and a given line AB in point P.

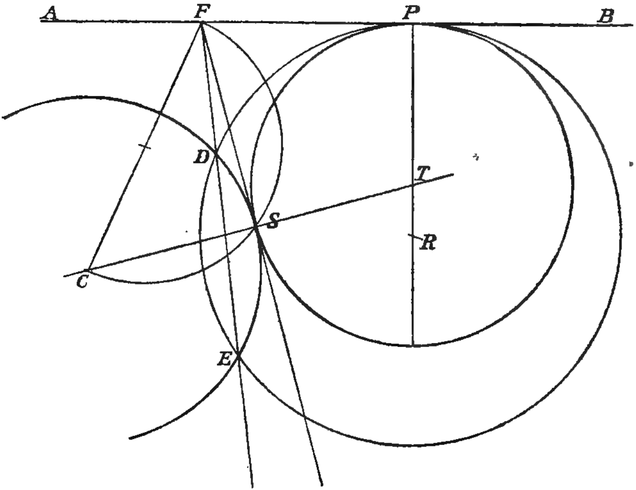


FIG. 51.

Draw PR at right angles to AB. With R as centre, and radius RP, describe a circle cutting the given circle in points D and E. Draw a line through points D and E, meeting AB in F. From F draw a tangent to the circle C, having the point of contact S. Draw the line CS, meeting PR in T, the centre of the circle required.

(75) To draw a circle to pass through two given points P and Q, to touch a given circle C.

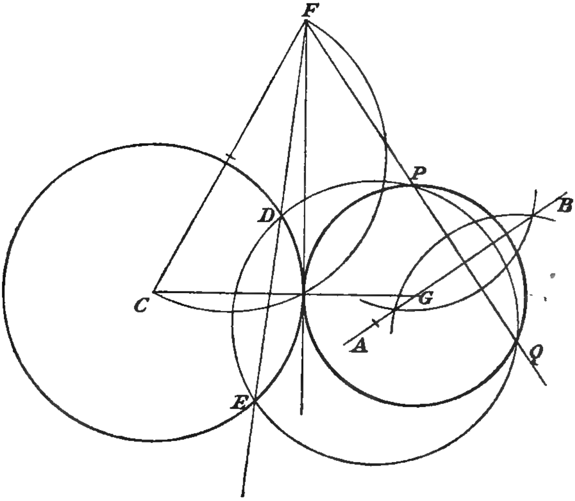


FIG. 52.

Draw AB bisecting at right angles PQ. Take any point on AB as centre, and describe a circle passing through P and Q, cutting the circumference of the circle C in points D and E. Draw a line through D and E to meet PQ produced in F. From F draw a tangent to the circle C. From the centre of the circle C draw a line through the point of contact to meet AB in G, the centre of the circle required.

(76) To draw a circle passing through two given points C and D, and tangential to a given straight line AB.

Join DC, and produce the line to meet AB in E. EF is a mean proportional between EC and ED. Draw FO at right

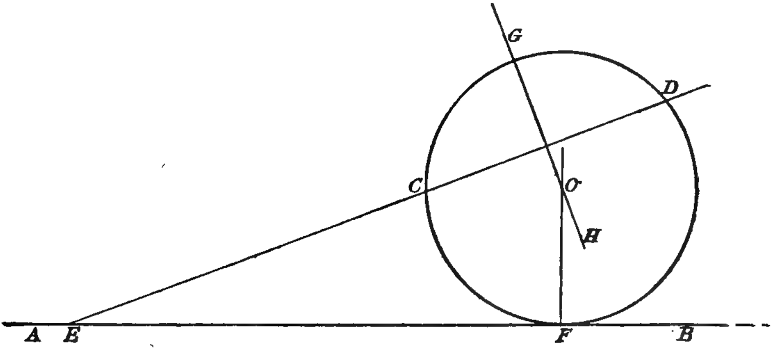


FIG. 53.

angles to AB, meeting the line GH, drawn bisecting CD at right angles in point O, the centre of the circle required.

Note.—For mean proportional, see Problem 128.

(77) To describe a circle tangential to a given circle A and a given straight line BC, and passing through a given point P.

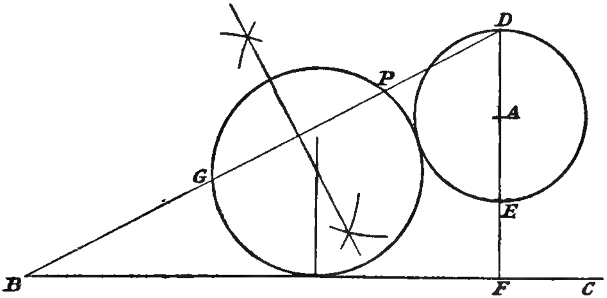


FIG. 54.

Through the centre of the circle A draw a line perpendicular to BC, cutting the circumference of the circle A in points D and E, and the line BC in F. Draw a line from D through point P, and produce it indefinitely. Find a fourth proportional DG, greater to the three lines DF, DE, and DP. A circle drawn passing through the points G and P, tangential to BC, by Problem 76, is the circle required.

Note.—For fourth proportional, see Problem 135.

(78) To describe a circle passing through a given point A, to touch and enclose two given circles.

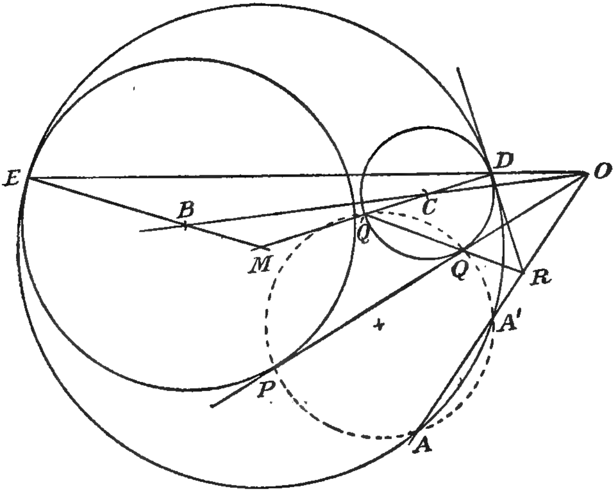


FIG. 55.

Let A be the given point, B and C the centres of the given circles. Draw the common tangent PQ through the external centre of similitude O. Describe a circle passing through PQA cutting OA in A′ and the circle C in Q′. Draw a line through QQ′ meeting AA′ in point R. Draw the tangent RD to the circle C. From O draw a line through D, meeting the second circle in the farther point E. Points D and E are points of contact of the required circle. Lines EB and DC meet in point M, the centre of the required circle.

If the other tangent from R be taken, a circle is obtained touching the given circles externally and passing through point A.

If the tangent passing through the internal centre of similitude (instead of the tangent PQ), circles are obtained touching one of the given circles externally and the other internally.

(79) To describe a circle enclosing any three given circles A, B, and C tangentially.

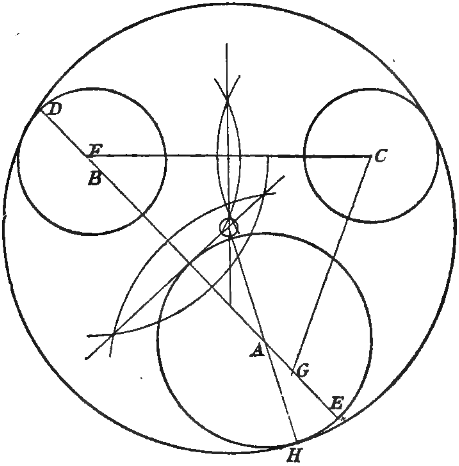


FIG. 56.

Join the centres of the two largest circles A and B, produce this line to meet their circumferences in D and E. From D and E set off DF, EG equal to the radius of the circle C. Join the centre of the circle C with points F and G. Bisect CF and FG by lines meeting in O, the centre of the required circle. The radius OH is found by drawing a line from O, through the centre of the circle A, meeting the circumference in H.

N.B.—The above problem is an approximation. It may be accurately worked by describing circles with FB and AG as radii, point C the centre of the smaller circle being taken as a given point and applying problem 78. It may be also accurately worked by finding the line of similitude, poles, and radical centre of the circles.

(80) To inscribe a circle within a trapezium ABCD, having pairs of equal adjacent sides.

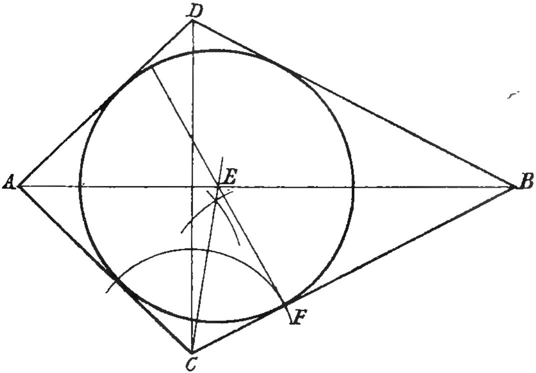


FIG. 57.

Bisect the angles BCA and DBC by lines meeting in E, the centre of the trapezium. Draw EF at right angles to BC. With E as centre, and radius EF, describe the circle required.

(81) Within a sector to inscribe a semicircle.

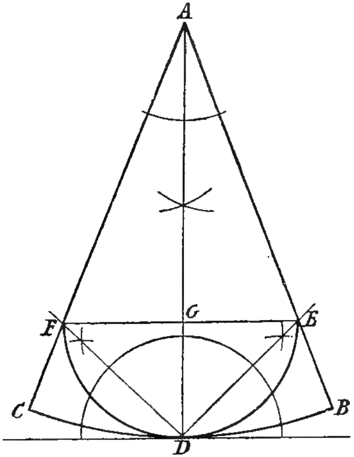


FIG. 58.

Bisect the angle BAC by a line AD; at D draw a tangent by Problem 53. Bisect the right angles formed by the tangent and AD by lines meeting BA and AC in points E and F. Join EF by a line meeting AD in G. G is the centre of the required semicircle, and GD is the radius.

A semicircle may be placed within an isosceles triangle by the same method.

(82) Within a sector to inscribe a circle.

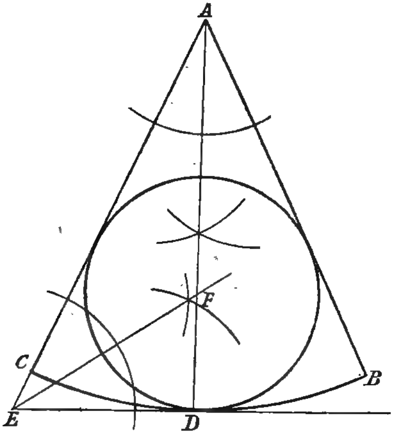


FIG. 59.

Bisect the angle BAC by a line AD; at D draw a tangent DE, by Problem 53. Produce AC, meeting the tangent in E. Bisect the angle DEA. F is the centre of the required circle, and FD is the radius.

(83) Within a sector to inscribe a square.

Draw AD at right angles to AB, and equal in length. Join DC by a line cutting the arc of the sector in point E. Draw EF parallel to AB. EF is a side of the required square.

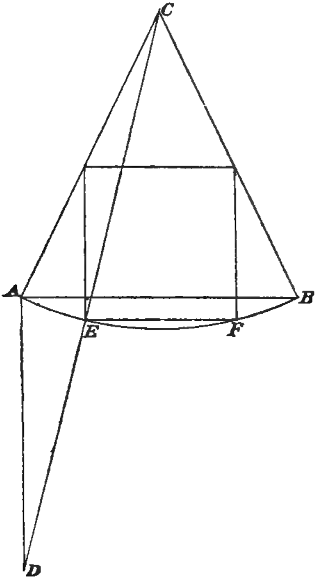


FIG. 60.

(84) To inscribe a square within a given circle.

Draw two diameters of the circle at right angles to each other, meeting the circumference of the circle in points AC and BD. Join the points.

(85) To describe a square about a given circle.

Find points ABCD as in the last problem. With these points as centres describe arcs with a radius equal to that of the circle, and intersecting each other in points EFGN. Join the points.

(86) To inscribe two equal circles within a square.

Draw a diagonal of the square, thus dividing the square into two equal isosceles triangles. Within each triangle place a circle.

(87) To inscribe the largest possible semicircle within a square ABCD.

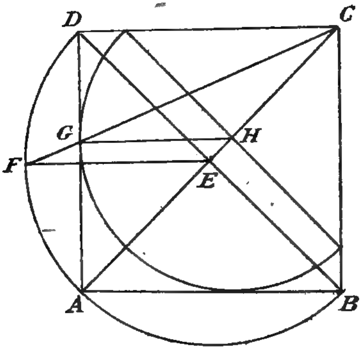


Fig. 61.

Draw the diagonals AC and DB. Describe a semicircle on DB. Draw EF at right angles to AD. Join F and C. Through point G draw GH parallel to FE. H is the centre and HG the radius of the semicircle required.

(88) To inscribe four equal semicircles, having their

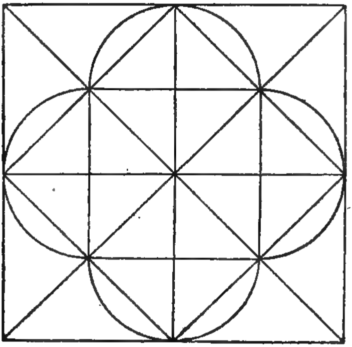


Fig. 62.

diameters adjacent, within a square. Each arc to touch one side of the square.

Draw the diagonals which divide the square into four equal triangles. Inscribe a semicircle within each triangle.

(89) To inscribe four equal semicircles, having their diameters adjacent, within a given square. Each arc to touch two sides of the square.

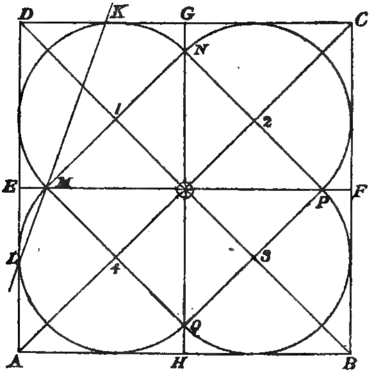


FIG. 63.

Draw the diagonals AC, BD, and the diameters EF, GH, of the given square. Bisect DG in K, and EA in L. Join KL by a line intersecting EF in M. With O as centre, and radius OM, set off ON, OP, OQ. Join these points by lines (which are the adjacent diameters), meeting the diagonals of the square in points 1, 2, 3 and 4, the centres of the required semicircles.

(90) To inscribe four equal circles within a given square, each circle touching two others and two sides of the square.

Draw the diagonals and diameters of the square, meeting in E; also the remaining diagonals of the four smaller squares, meeting the diagonals of the given square in points 1, 2, 3 and

4. Join 1, 2, meeting GE in point 5. 1, 2, 3 and 4 are the centres, and 1, 5 is the radius required.

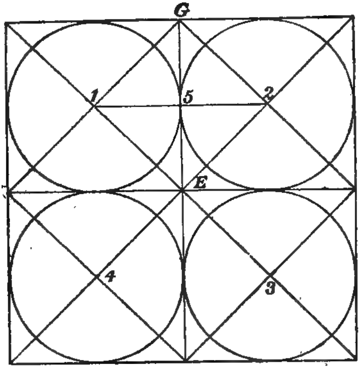


FIG. 64.

(91) To inscribe four equal circles within a given square, each circle touching two others and one side of the square.

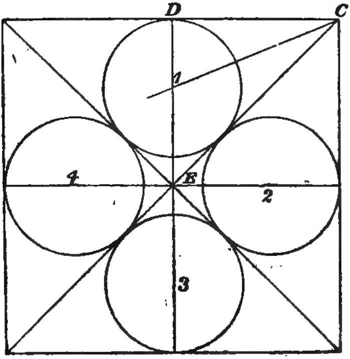


FIG. 65.

Draw the diagonals and diameters of the given square, meeting in E. Bisect one of the angles of 45°, as DCE, the line bisecting meeting nearest diameter in point 1. From E set off E1 on each semi-diameter in points 2, 3 and 4, the centres of the required circles. 1, D, is the radius required.

(92) To inscribe eight equal circles within a square.

Draw the diagonals and diameters of the square, thus dividing the square into eight equal isosceles triangles. Within each triangle place a circle.,

(93) To inscribe three equal circles within an equilateral triangle, each circle touching two others and one side of the triangle.

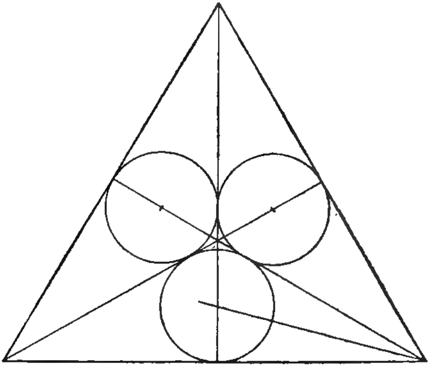


FIG. 66.

Find the centre of the triangle, and draw lines from the corners of the triangle to the centre, thus obtaining three equal triangles; in each triangle place a circle.

(94) To inscribe three equal circles within an equilateral triangle, each circle touching two others and two sides of the triangle. (See Fig. 67, p. 54.)

Find the centre of the triangle. Through the centre draw lines from the corners of the triangle, meeting the opposite sides, thus obtaining three equal trapezia. Within each trapezium inscribe a circle.

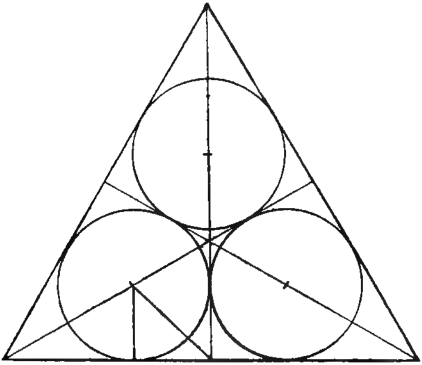


Fig. 67.

(95) To inscribe three circles in any triangle, the circles touching each other and one side of the triangle.

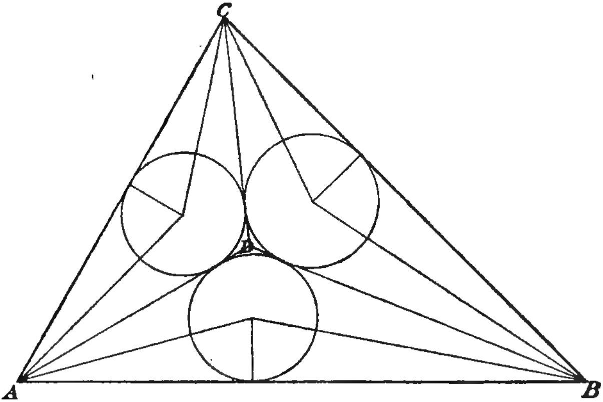


Fig. 68.

Find D, the centre of the triangle. The lines DA, DB and DC divide the given triangle into three elementary triangles. Within each triangle inscribe a circle.

(96) To inscribe three circles in any triangle, each circle touching each other and two sides of the triangle.

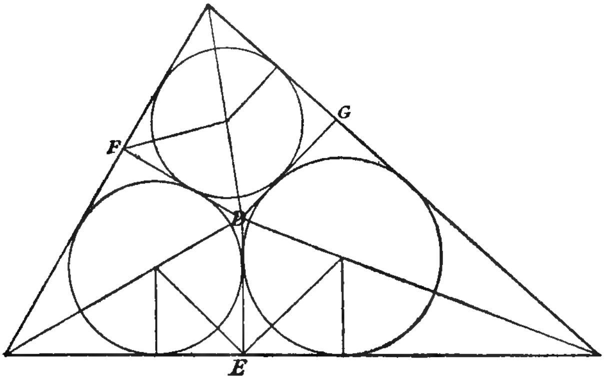


FIG. 69.

Find D, the centre of the triangle. Draw lines DE, DF and DG at right angles to the sides of the triangle, dividing the triangle into three trapezia. Within each trapezium inscribe a circle.

(97) To inscribe six equal circles within an equilateral triangle.

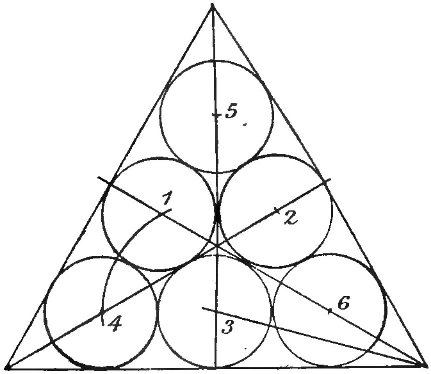


FIG. 70.

Proceed as in Problem 93 for the first three. From centres 1, 2 and 3, and with a radius equal to 3, 1, set off points 4, 5 and 6. These points are the centres of the remaining three circles required.

(98) To inscribe six equal circles within an equilateral triangle, each circle touching one side of the triangle.

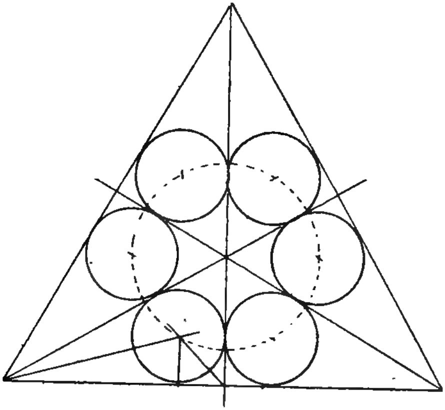


FIG. 71.

Draw lines bisecting each angle, thus dividing the equilateral triangle into six equal triangles. Within each triangle place a circle.

(99) To inscribe a triangle within a circle, having angles of a given number of degrees,—in this case 45°, 60°, and 75°.

At any point A in the circumference of the given circle draw a tangent DE. The angle DAB = 45°, and the angle EAC = 60°. Join BC. The angle at B = 60°, at C = 45°, at A = 75°.

Note.—By the same method as shown in this problem, a triangle may be inscribed within a circle similar to a given triangle. (4 Euc. IV.)

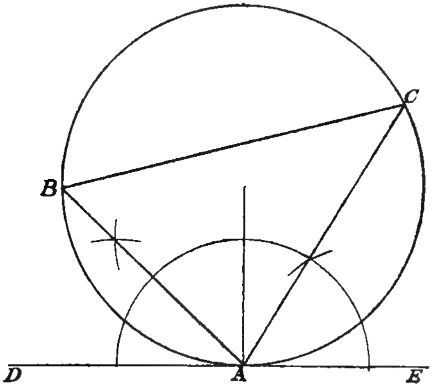


FIG. 72.

(100) To describe a triangle about a circle, having angles of a given number of degrees,—in this case 60°, 45°, and 75°.

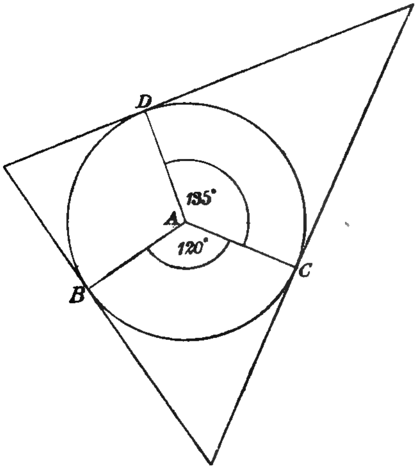


FIG. 73.

Make the angle $BAC = 180° - 60° = 120°$.
" " $DAC = 180° - 45° = 135°$.

The sides of the triangle are tangents to the circle at points B, C and D. (3 Euc. IV.)

Note.—By the same method as shown in this problem a triangle may be described about a circle similar to a given triangle.

(101) To inscribe three equal semicircles having their diameters adjacent within an equilateral triangle, each semicircle touching one side of the triangle.

Find the centre of the triangle, and draw lines from the corners of the triangle through the centre, meeting the sides in A, B and C, thus dividing the triangle into three equal triangles. In each triangle place a semicircle by bisecting the right angles at A, B and C.

(102) To inscribe three equal semicircles having their diameters adjacent within an equilateral triangle, each semicircle touching two sides of the triangle.

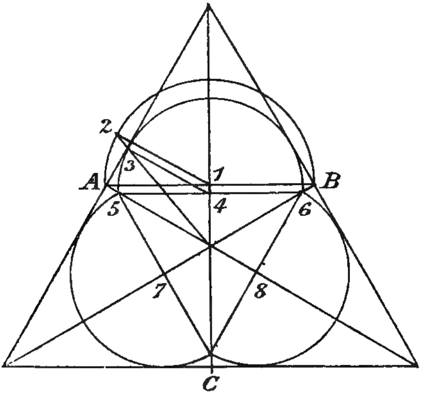


FIG. 74.

Find points A, B and C as in Problem 93. Join AB, and describe a semicircle on AB, with point 1 as centre. From 1 draw a line at right angles to the side of the triangle, meeting the semicircle in point 2. Draw a line from 2 to the centre of the triangle, meeting the side in point 3. From 3 draw a line 3, 4 parallel to 1, 2. Through 4 draw a line 5, 6 parallel to AB. On 5, 6 construct an equilateral triangle. The sides are the adjacent diameters. Points 4, 7 and 8 are the centres of the required semicircles.

(103) To construct a regular polygon on a given line AB.

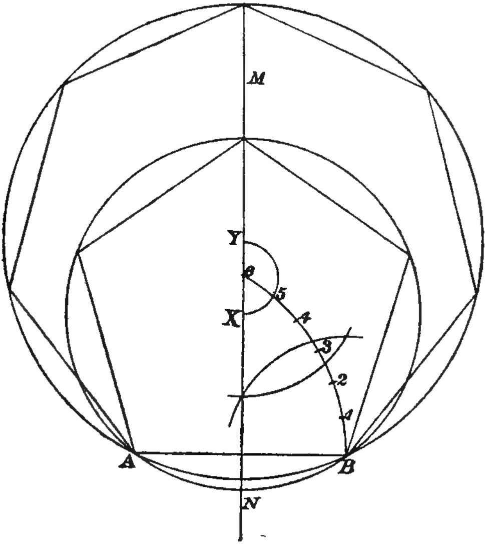


FIG. 75.

Bisect AB by a line MN at right angles. With A as centre, and radius AB, describe an arc B6; point 6 is the centre of a hexagon, having AB as one side. Divide the arc B6 into six equal parts, in points 5, 4, 3, 2 and 1. With 6 as centre describe the arc 5X. Take X as centre, and with radius XA, describe a circle. AB is the side of a pentagon inscribed within the circle. To construct a heptagon, proceed as in the pentagon, but describe the arc 5Y above. Y is the centre, and YA the radius of a circle, that AB will measure seven times round its circumference. It will be evident any regular polygon may be thus constructed.

N.B.—The above problem is an approximation, but useful for practical purposes.

(104) To divide the circumference of a given circle A into equal arcs by means of the compasses only.

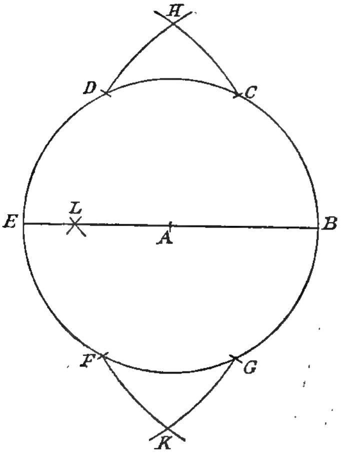


FIG. 76.

The radius AB, set off from B, divides the circumference into six equal parts, and therefore into three and two. With the chord of $\frac{1}{3}$ the circumference, describe arcs from B and E as centres, the arcs intersecting in H and K. AH and AK are chords of $\frac{1}{4}$ the circumference, and arcs described from H and K as centres, with radius AB, again bisect the quadrant; from points G and C as centres, with AH and AK as radii, describe arcs intersecting in L. The radius AE is medially divided in L; AL is the chord of $\frac{1}{10}$ of the circumference, and by taking alternate points, we have the circumference divided into five equal parts.

(105) Given the perimeter of a regular polygon, to construct it.

Divide the perimeter into as many equal parts as the polygon has sides. On one of the parts construct the polygon, by Problem 103.

(106) To construct a regular hexagon on a given line AB.

With A and B as centres, and radius AB, describe arcs meeting in point O. With O as centre, and radius OA, describe a circle. Set off AB round the circumference, and join the points.

(107) To find the angles the sides of a regular polygon make with each other.

If y = number of sides, and x = number of degrees between the sides,

$$\therefore \frac{2y-4}{y} \times 90 = x.$$

For example, find the angle between the sides of a regular pentagon.

$$\frac{10-4}{5} \times 90 = \frac{6 \times 90}{5} = 108^\circ \text{ between the sides.}$$

(108) To inscribe any regular polygon within a circle. (See Fig. 77, p. 62.)

Divide the diameter AB into as many equal parts as the required polygon has sides,—in this case five.

With A and B as centres, and radius equal to the diameter, describe arcs intersecting in M. From M draw a line through the second division on the diameter, to meet the circumference of the circle in point C. AC is a side of the polygon required, —in this case a pentagon.

N.B.—The above problem is an approximation, but useful for practical purposes.

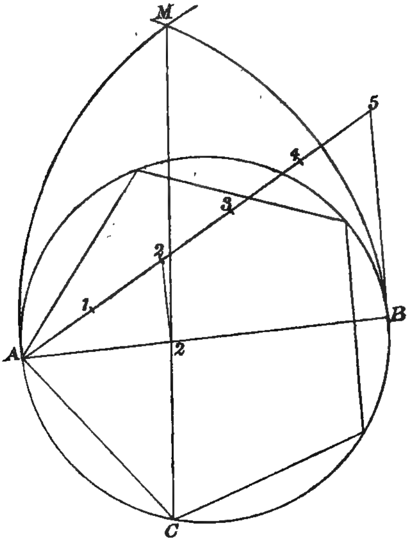


FIG. 77.

(109) To inscribe a regular heptagon within a circle.

Divide the diameter into seven equal parts, and proceed as with the pentagon in Problem 108.

(110) To inscribe a regular hexagon within a circle.

Set off the radius of the circle round the circumference, and join the points.

(111) To inscribe a regular octagon within a circle.

Draw a diameter AE and bisect it by a line CG at right angles. Bisect the right angles formed by these lines. These lines meet the circumference in BDF and H. Join the points.

(112) Within a given circle to inscribe any number of equal circles, each circle touching two others and the circumference of the given circle,—in this case five.

Divide the circumference of the circle into the same number of equal parts as circles you wish to inscribe, by Problem 108. Join the centre and the points in the circumference of the circle. In other words, we have the circle divided into the same number of equal sectors as circles required. In each sector inscribe a circle. (See Problem 82.)

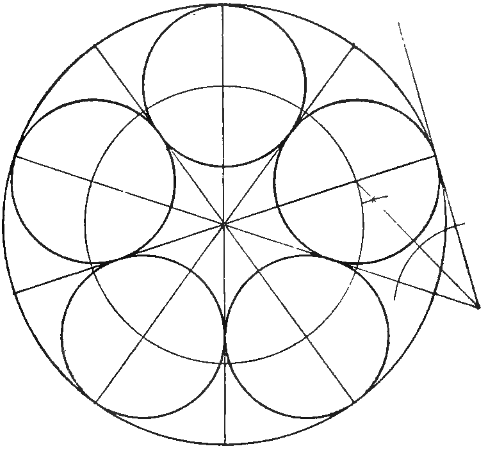
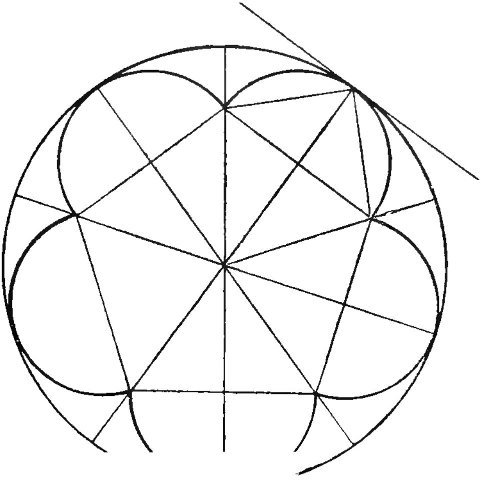


FIG. 78.

(113) Semicircles having their diameters adjacent



may be inscribed within a circle by placing a semi-circle in each sector. (See Problems 81 and 112.)

(114) To inscribe any number, as three, equal circles within a given circle, equidistant from each other and the circumference of the given circle.

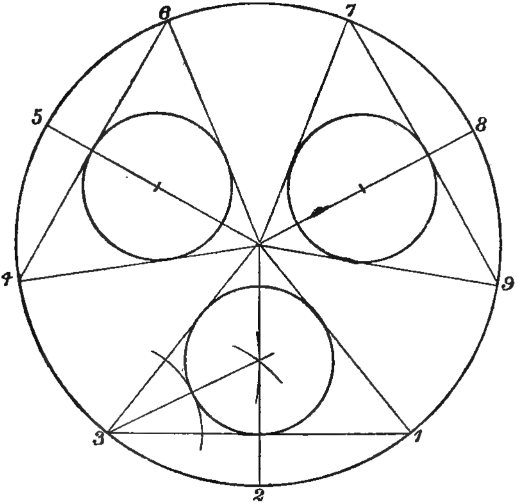


Fig. 80.

Divide the circle into three times the number of equal sectors as circles required,—in this case nine. Join points 1 and 3, 4 and 6, 7 and 9. In each of these triangles inscribe a circle.

(115) To describe any regular polygon about a circle,—in this case a regular hexagon.

Divide the circle into the same number of sectors as the polygon has sides. A line bisecting one of the angles meets the circumference of the circle in point A. At point A draw a tangent to the circle, meeting two of the radii in B and C. With O the centre of the circle as centre, and radius OB, describe a circle intersecting the radii continued in points DEFG. Join the points.

(116) Within a polygon to place another having a given side.

Divide the polygon into equal isosceles triangles, and proceed as in Problem 26.

Note.—By this method any number of concentric polygons (polygons having the same centre) may be drawn.

(117) To inscribe a square within a regular polygon, —in this case within a pentagon.

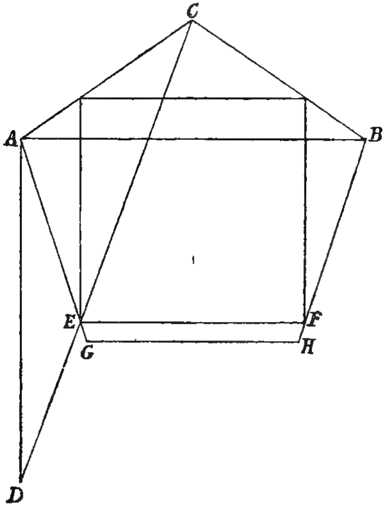


FIG. 81.

Draw AD at right angles to the diagonal AB, and equal in length to it. Join DC by a line intersecting AG in point E. Draw EF parallel to GH. EF is a side of the required square.

(118) To inscribe a square in any regular polygon having an even number of sides.

Draw a diagonal AB, and bisect it by a diameter CD. Bisect the right angles so formed by lines meeting the sides of the polygon in points EFGH. Join the points.

(119) To inscribe as many equal circles within a polygon as the polygon has sides, each circle touching two others and one side of the polygon.

Divide the polygon into equal isosceles triangles, and in each triangle inscribe a circle, by Problem 63.

120) To inscribe as many equal semicircles within a polygon as the polygon has sides, each semicircle touching one side of the polygon and having their diameters adjacent.

Divide the polygon into equal isosceles triangles, and in each triangle place a semicircle, by Problem 81.

(121) To inscribe as many equal circles within a polygon as the polygon has sides, each circle touching two others and two sides of the polygon.

Divide the polygon into equal trapezia, and within each trapezium inscribe a circle, by Problem 80. By joining two centres the radius is obtained.

(122) To inscribe the largest possible equilateral triangle in a regular polygon.

From one of the angular points A draw a line AB, bisecting the angle between the adjacent sides. From A draw lines making 30° with AB, meeting two sides of the polygon in points C and D. ADC is the triangle required.

(123) To inscribe the largest possible equilateral triangle in a regular hexagon.

By drawing lines joining the alternate angles the required equilateral triangle is inscribed within the hexagon.

(124) Within a square to inscribe the largest possible equilateral triangle.

Draw a diagonal AC. From A draw lines making 30° with AC, and meeting two sides of the square in points D and E. ADE is the triangle required.

(125) In a given square to inscribe the largest possible isosceles triangle, having a given base.

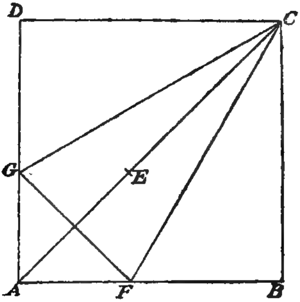


Fig. 82.

Let ABCD be the given square. Draw the diagonal AC. From A set off AE, equal to the base of the required triangle. Bisect AE by a line at right angles, intersecting AB and AD in points F and G. The triangle FCG is the one required.

(126) In a given square to inscribe a square, one corner of which shall coincide with a given point E in a side of the given square.

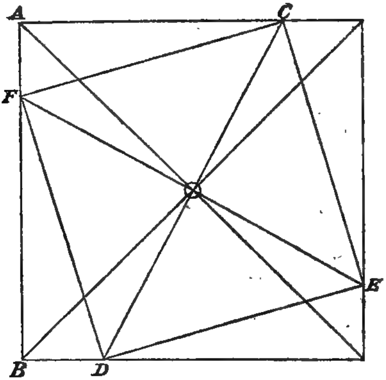


Fig. 83.

Draw a line from E, the given point, through the centre of the square, meeting AB in F. EF is a diagonal of the required square. With O as centre, and radius OE, describe a circle intersecting the other sides of the given square in points C and D.

(127) Within a square to inscribe a regular octagon.

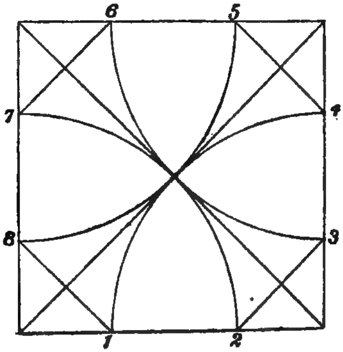


Fig. 84.

The alternate sides of the octagon to coincide with the sides of the square.

With the corners of the square as centres, and radius equal to half the diagonal, describe arcs meeting the sides of the square in points 1 – – – – – – 8, the corners of the required octagon.

(128) To find a mean proportional to two given straight lines AB and BC.

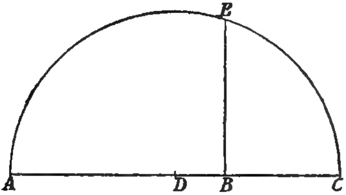


FIG. 85.

Draw a line AC, equal in length to the sum of AB and BC. Bisect AC in D, and describe a semicircle on AC. Draw BE perpendicular to AC. This ordinate BE is a mean between the segments AB and BC.

$$\therefore AB : BE :: BE : BC. \quad \text{(13 Euc. VI.).}$$

(129) To divide a given straight line AB harmonically.

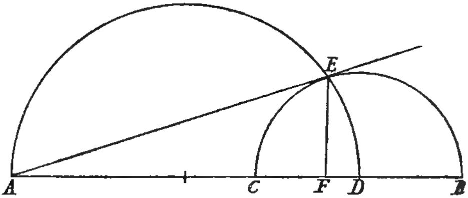


FIG. 86.

In AB take any point C, and bisect CB in D. Describe a semicircle on CB, and draw a tangent from A to the semicircle. From point of contact E draw EF perpendicular to AB.

$$\therefore AB : AC :: BF : FC.$$

(130) To find a harmonic mean to two lines AB and BC.

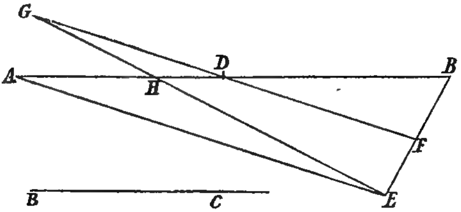


FIG. 87.

From B in AB set off BD equal to BC. Assume any point E outside. Join AE and BE. Draw a line through D parallel to AE, cutting BE in F, and produce the line indefinitely towards G. Make DG equal to DF. Join GE by a line cutting AB in H. BH is the harmonic mean between the two lines BD and BA.

$$\therefore BD + HA = BA - DH.$$

(131) To determine the roots $\sqrt{2}$, $\sqrt{3}$, $\sqrt{4}$, $\sqrt{5}$, $\sqrt{6}$,

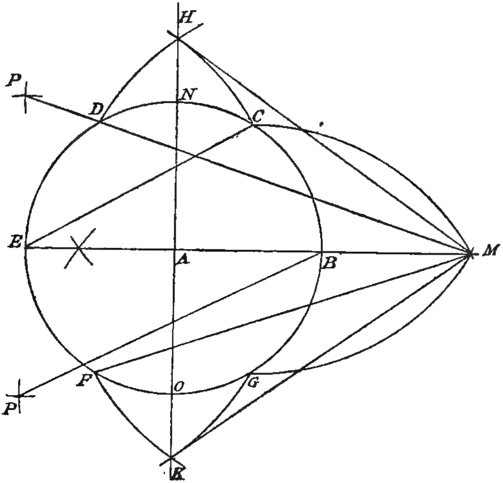


FIG. 88.

$\sqrt{7}$, $\sqrt{8}$, $\sqrt{9}$, $\sqrt{10}$, the radius of a given circle A being taken as unity.

The points A . . . . K, are found by Problem 104. From G and C as centres, and CG as radius, describe arcs intersecting in M; and from NO and E as centres, with AB as radius, describe arcs intersecting in P. Then AH $= \sqrt{2}$, CE $= \sqrt{3}$, BE $= \sqrt{4}$, PB $= \sqrt{5}$, HM or KM $= \sqrt{6}$, FM $= \sqrt{7}$, HK $= \sqrt{8}$, EM $= \sqrt{9}$, PM $= \sqrt{10}$.

(132) Find $\sqrt{2}$, $\sqrt{3}$, $\sqrt{5}$, $\sqrt{6}$, with the pencil compasses only, the unit being 1″—*i.e.*, no line is to be drawn. Put letters to show the different lines.

Describe a circle with an inch radius, and proceed as in Problem 131.

(133) A line CD represents 9. Obtain by construction a line which will represent the square root of CD.

Divide CD into nine equal parts, and find a mean proportional DE to CD, and $\frac{1}{9}$th of CD. DE is the square root required.

(134) To find a third proportional—1st, less, and 2nd, greater—to two given straight lines AB and BC.

(1*st*) At A in AB draw a line AD at any angle with it, and equal to BC, and join BD. From A as centre, radius AD, describe an arc cutting AB in point E, and from E draw a line EF parallel to BD, cutting AD in point F. AF is the required third proportional less—*i.e.*, AB : BC : : BC : AF.

(2*nd*) At A in AB draw a line AD at any angle with it, and equal to BC. Join BD, and produce AB and AD indefinitely.

From A as centre, with AB as radius, describe an arc intersecting AD produced in G, and from G draw a line GH parallel to BD, meeting AB produced in point H. AH is the required third proportional greater—*i.e.*, BC : AB : : AB : AH. (2 Euc. VI.).

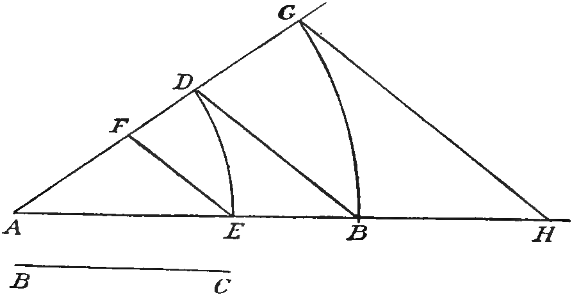


FIG. 89.

(135) To find a fourth proportional to three given straight lines, AB, BC, and CD.

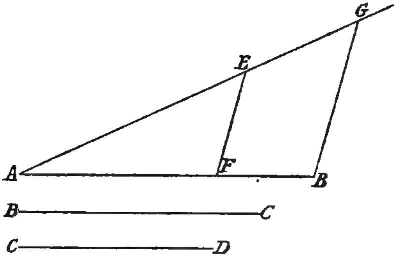


FIG. 90.

From A in AB draw a line AG at any convenient angle. From A set off AF equal to CD, and AE equal to BC. Join EF. From B draw a line BG parallel to EF. AG is the fourth proportional greater.

$$\therefore CD : BC :: AB : AG. \quad (2 \text{ Euc. VI.}).$$

If points BE be joined and a line from F be drawn parallel to BE meeting AE in point H, AH will be a fourth proportional less.

∴ AB : BC : : CD : AH.

(136) From a point A outside a given circle, to draw a line to meet the circle in points C and D, so that AD may be divided by the circumference of the circle in two parts of a given proportion.

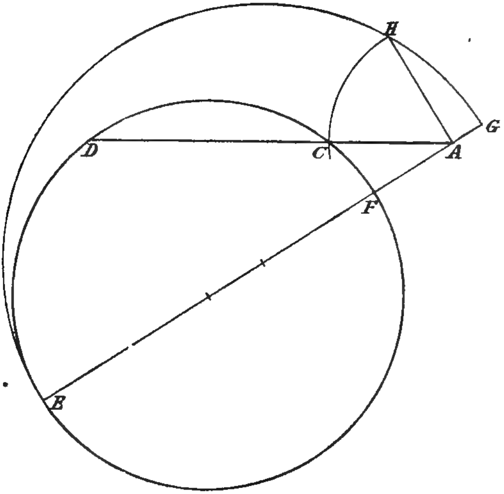


FIG. 91.

Draw a diameter EF from point A. Draw also any straight line, and divide it into the parts required,—in this case three equal parts. AG is a fourth proportional less to $\frac{1}{3}$ of the line, the whole line, and AF. Find a mean proportional AH to AG and AE. AC equals AH. Draw a line from A through C, meeting the circumference in D. The line CD is $\frac{2}{3}$ the length of AD.

∴ AC : CD : : 1 : 2.

(137) To divide a line AB medially, or in extreme and mean proportion.

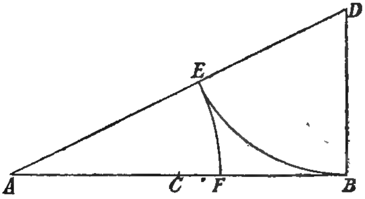


FIG. 92.

Bisect AB in C. Make BD equal to BC, and at right angles to AB. Join DA. With D as centre, and radius DB, describe the arc BE; with A as centre, and radius AE, describe the arc EF.

$$\therefore BF : FA :: FA : AB. \quad (11 \text{ Euc. II.}).$$

Note.—If the problems in proportionals be worked to a scale of units the proportions may be practically proved.

(138) To draw a triangle equal in area to a given regular polygon,—in this case a pentagon ABCDE.

Divide the polygon into equal isosceles triangles. The base of the triangle required will be equal in length to five times one side, and the altitude equal to the altitude of one of the isosceles triangles.

(139) To draw a triangle equal in area to a given polygon, the base to coincide in direction with AB, and its vertex at the opposite angle D.

(*a.*) Draw EF parallel to DA, meeting AB produced. The triangle AFD is equal to the triangle AED (triangles on the same base and between the same parallels). (37 Euc. I.). Draw CG parallel to DB, meeting AB produced. The triangle

ABG is equal to the triangle DBG. ∴ the triangle DFG is equivalent to the five-sided figure.

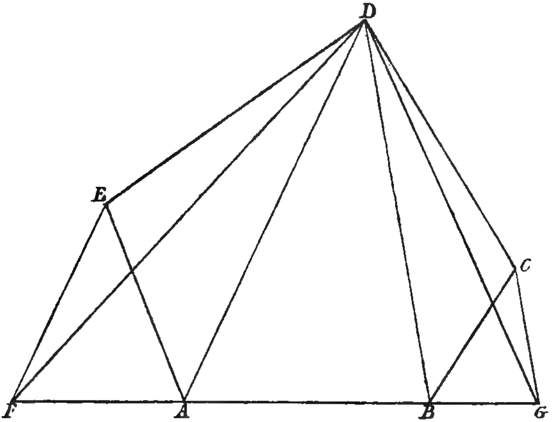


FIG. 93.

(*b.*) When the given polygon has a re-entering angle, as at C.

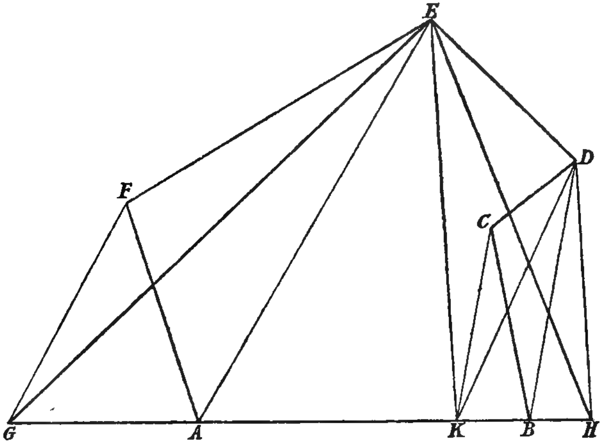


FIG. 94.

It is the best to begin by drawing CK parallel to DB, and join DK. From D draw a line parallel to EK, meeting AB produced in H. The triangle KEH is equal in area to the figure BCDEK. Proceed with the problem as in case (*a.*). ∴ the triangle GEH is equivalent to the six-sided polygon.

(140) To draw a square equal in area to a given triangle.

Find a mean proportional between the base and half the altitude of the triangle. The mean proportional is the side of the square required.

(141) To draw a triangle of any given area.

Draw an oblong equal to the given area, and a triangle equal in area to the oblong.

(142) To draw a rectangle equal in area to a given triangle.

The sides of the oblong are equal to the base and half the altitude of the triangle respectively.

(143) To divide a triangle ABC into two equal parts or areas by a line drawn from one corner.

Bisect one side AB of the triangle in D. The line joining D and C divides the triangle into two equal areas.

Note.—By the same method a triangle may be divided into any number of equal areas. If three equal areas, divide AB into three equal parts and draw lines from C to the divisions on AB. If five equal areas, divide the base into five equal parts, &c.

(144) To bisect a triangle by a line drawn parallel to the altitude.

Bisect AB in E, and draw the altitude CD. Find a mean proportional to BD and BE. Make BF equal to the mean proportional found. Draw FG parallel to the altitude; this line divides the triangle into two equal areas.

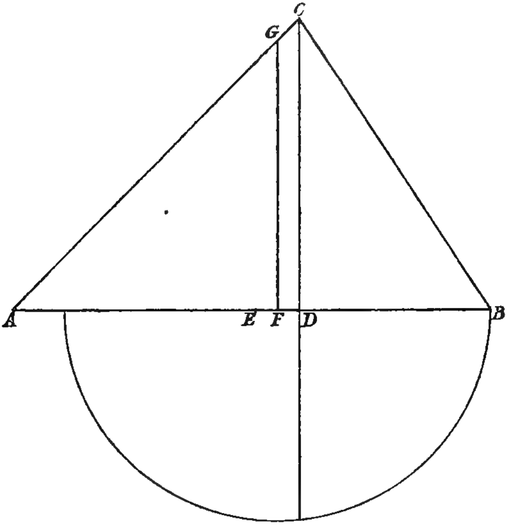


FIG. 95.

(145) To bisect a triangle by a line drawn parallel to one of its sides.

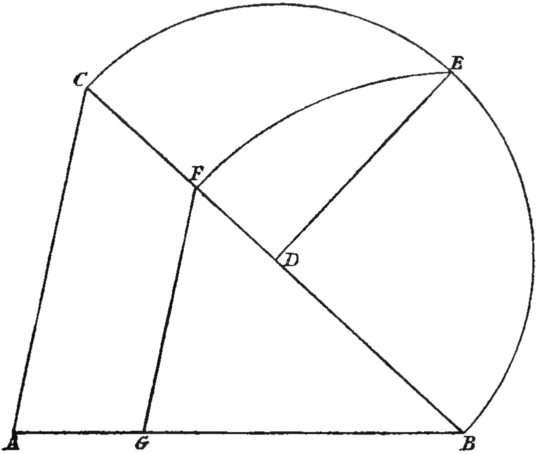


FIG. 96.

Bisect BC in D, and describe a semicircle on BC. Draw DE at right angles to BC. With B as centre, and radius BE, describe an arc meeting BC in F. FG drawn parallel to AC bisects the triangle.

(146) To divide a triangle into any number of equal parts, or having a given ratio, by lines drawn from one angle to the opposite side.

Divide the base of the triangle into the required number of equal parts, and from the points thus found draw lines to the apex of the triangle. For a given ratio, as 3 : 2, divide the base of the triangle into five equal parts—*i.e.*, 3 + 2. From the second division draw a line to the apex, which divides the triangle into the given ratio.

(147) To divide a triangle ABC into any number of equal areas by lines drawn from a point D within the triangle. In this case three.

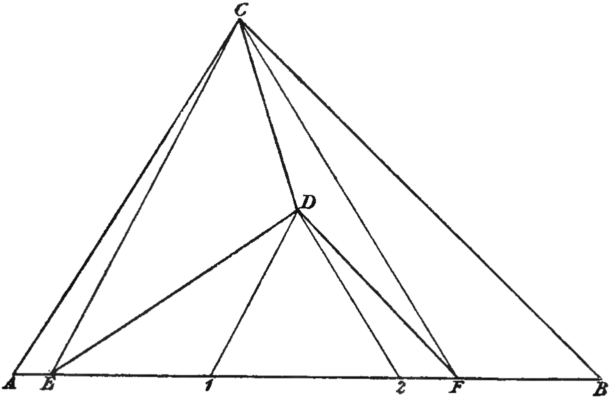


FIG. 97.

Divide AB into the required number of equal parts, as 1 and 2. Draw lines D1 and D2. Draw CE parallel to D1, and CF parallel to D2. Join DE, DC, and DF, by lines which divide the triangle as required. If the lines CE and CF fall outside the triangle, the solution is obtained by Problem 163.

(148) To divide a triangle ABC into three equal areas by lines drawn from the angles, meeting at a point within the triangle.

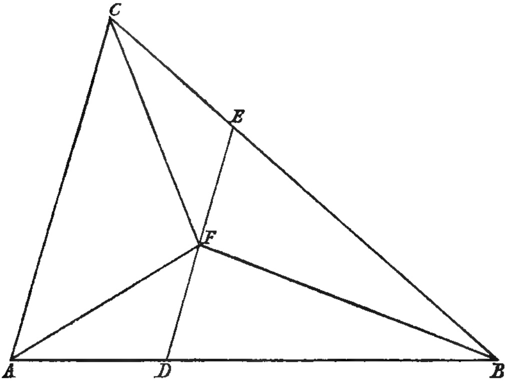


FIG. 98.

Divide AB into three equal parts. Draw DE parallel to AC. Bisect DE in F. Join F and the points ABC by lines which divide the triangle as required.

(149) To draw a triangle standing on the same line

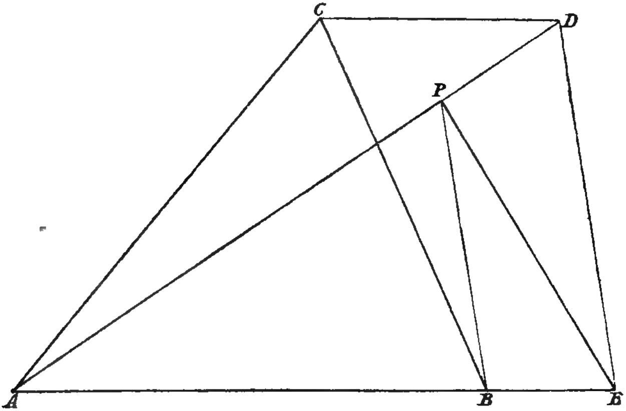


FIG. 99.

as a given triangle ABC, and equal in area to it, but having a given vertex P.

Draw from C a line parallel to the base, and a line from A through P, meeting the line drawn from C in D. Join PB, and draw DE parallel to PB, meeting AB produced in point E. EPA is the triangle required.

(150) To draw a triangle when the vertical angle, base, and area are given.

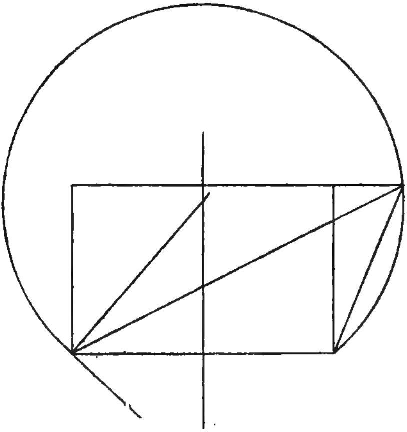


FIG. 100.

On the base draw a rectangle equal to twice the area of the triangle. Also, on the base as a chord, describe the segment of a circle to contain an angle equal to the given vertical angle. The point where the segment meets the side or the side produced of the rectangle, is the apex of the triangle required.

(151) To draw an equilateral triangle equal in area to a given triangle.

On one side of the given triangle ABC construct an equilateral triangle ADC. From B draw a line parallel to AC, meeting DA produced in E. A mean proportional AF, between

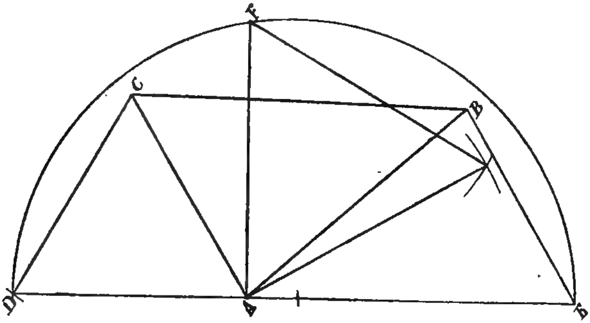


FIG. 101.

AD and AE, is a side of an equilateral triangle equal in area to the given triangle.

(152) To construct a rectangle on a given line equal in area to a given rectangle.

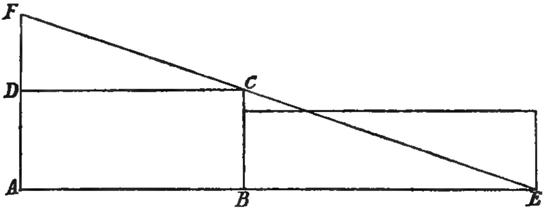


FIG. 102.

ABCD is the given rectangle. Produce AB, and make BE equal in length to the given line. Draw the line EC, meeting AD produced in point F. DF is the second side of the rectangle required.

(153) To draw a rhombus equal in area and having the same included angle as a given rhomboid.

Find a mean proportional between the two adjacent sides of a rhomboid. This mean proportional is the side of the rhombus required.

(154) To construct an oblong of a required area,—in this case 3 square inches.

Draw an oblong having its alternate sides 3″ and 1″.

(155) To construct a square of a given area.

Draw an oblong of the required area. A mean proportional between the alternate sides is the side of the square required.

(156) To construct a triangle on a given base AB, equal in area to a given triangle CDE.

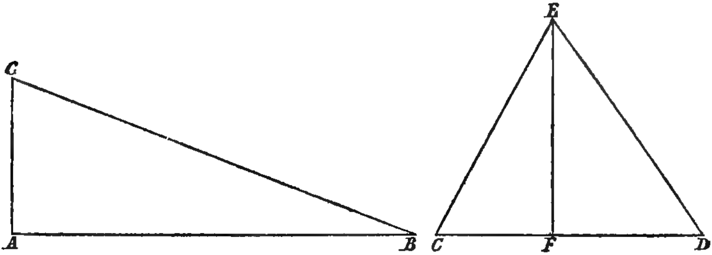


FIG. 103.

Draw the altitude EF. Make AG a fourth proportional less to AB, CD and EF. AG is the altitude of the required triangle, having AB as a base.

(157) To draw a square equal in area to the sum of the squares of $\frac{1}{2}$″, 1″, and $1\frac{1}{2}$″ sides.

Draw AB $\frac{1}{2}$″, and AC 1″, at right angles to each other. The hypotenuse BC is the side of a square equal to the squares on AB and AC. Draw BD $1\frac{1}{2}$″ at right angles to

BC. The line joining CD is the side of a square equal in area to the sum of the given squares. (47 Euc. I).

(158) To draw a square equal in area to a polygon.

Draw a triangle equal in area to the polygon by Problem 139. A mean proportional between the base and half the altitude of this triangle is the side of the square required.

(159) To state the area in square inches of any regular or irregular figure or polygon.

Reduce the given figure to a triangle of equal area by Problem 139, and proceed in the same way as given in Problem 158. The side of the square thus found measured in inches is the square root, which, multiplied by itself, is the area in square inches.

(160) To construct a triangle on a given altitude AB, equal in area to a given triangle CDE.

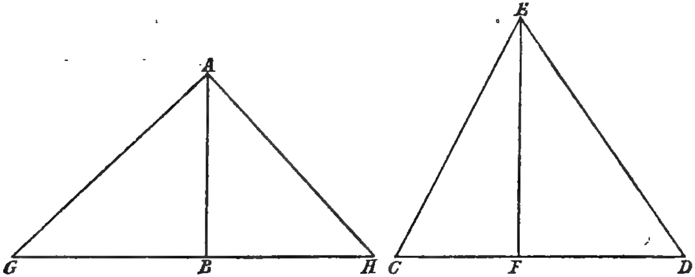


Fig. 104.

Find GH, a fourth proportional greater to the lines CD, EF and AB. GH is the base of the required triangle.

(161) To draw a rectangle on a given line, equal in area to a given square.

Find a third proportional less to the given line and a side of the given square. This third proportional is the second side of the rectangle required. See also Problem 152.

(162) To construct a triangle similar to a given one and equal in area to another given triangle.

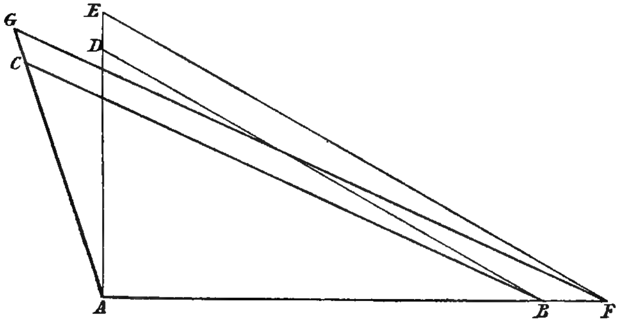


FIG. 105.

Find squares equal in area to each triangle by Problem 140. Draw a line from A at right angles to AB, and set off distances AD and AE, equal respectively to the sides of the squares. Join DB. From E draw a line parallel to DB, meeting AB produced in F. From F draw a line parallel to BC, cutting the line AC in G. AGF is the triangle required.

(163) Draw any trapezium ABCD, and divide it by a line drawn from C into two equal parts.

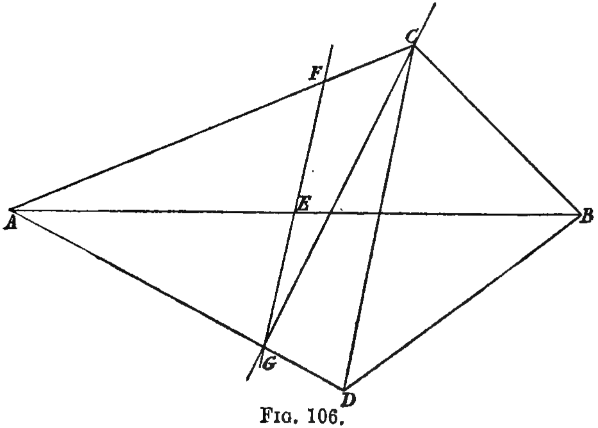


FIG. 106.

Draw the diagonals AB and CD. Bisect AB in point E. Draw FG through E parallel to CD. Join C and G by a line which divides the trapezium into two equal areas.

(164) To construct an isosceles triangle of a given area and having a given vertical angle.

Draw any triangle ABC, equal to the given area. Also an isosceles triangle DEF, having the given vertical angle. A triangle GHK, equal in area to ABC and similar to DEF, by Problem 162 is the one required.

(165) To divide a triangle ABC into any number of equal or proportionate parts by a line or lines drawn from a given point D in one side.

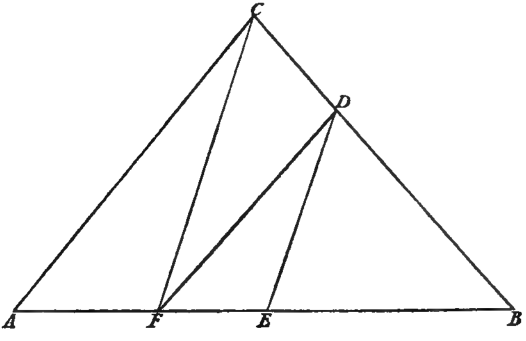


FIG. 107.

Divide AB into the required number of equal parts, or ratio, as at E. Draw CF parallel to DE. The line FD divides the triangle as required.

(166) To find a point O in a produced diagonal of a given square, from which, if a line be drawn

parallel to one side and to meet the farther adjacent produced side of the given square, it will form with the produced diagonal and side a triangle equal in area to the given square.

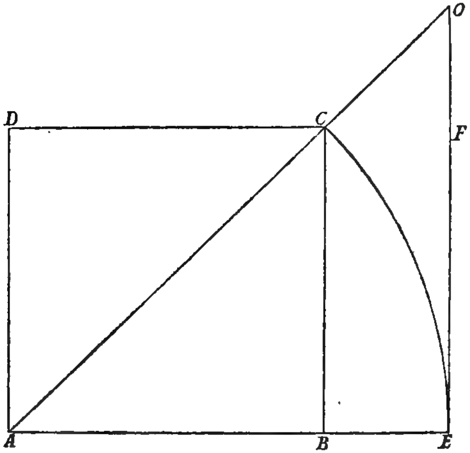


FIG. 108.

Draw the diagonal AC, and produce it. Produce AB, and make AE equal to AC. From E draw EF parallel to BC, meeting AC produced in O, the point required.

(167) To divide a square into three equal areas by lines drawn parallel to a diagonal.

Divide a side of the square, as DC, into three equal parts, and describe a semicircle on DC. Draw 2F, at right angles to DC. With D as centre, and radius DF, describe an arc meeting DC in G. Draw GH parallel to AC. The quadrilateral ACGH is one-third the area of the triangle ADC. Make CK equal to CG, and draw KL parallel to AC.

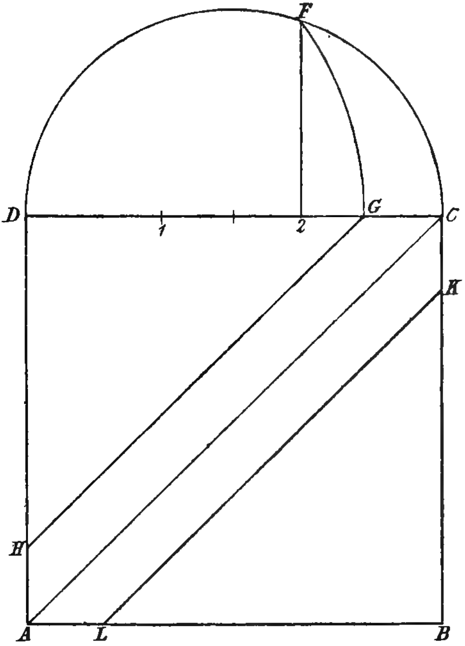


FIG. 109.

(168) To inscribe within a given square ABCD, another square having its angles in the sides of the first, and of a given ratio to the square ABCD.

Divide the square into the required ratio (as 3 : 2). Divide one side AD of the square into five equal parts, and through the third point draw a line parallel to AB. Find a side of a square equal in area to the parallelogram $\frac{3}{5}$ths the area of the given square. With the centre of the given square as centre, and radius equal to half a diagonal of a square $\frac{3}{5}$ths the area of the given one, describe a circle cutting the sides of the given square in points EFGH, the corners of the required square.

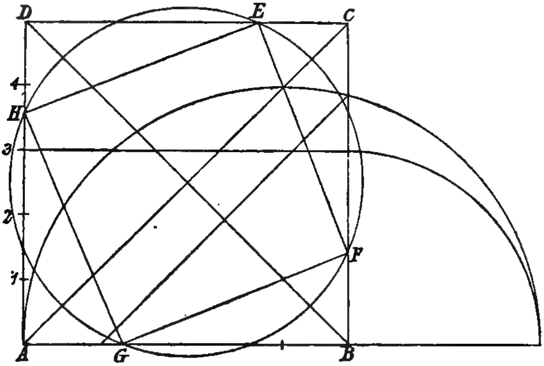


FIG. 110.

(169) To divide a parallelogram ABCD into two parts by a line drawn from a point E in one side, either equal or proportionate in area.

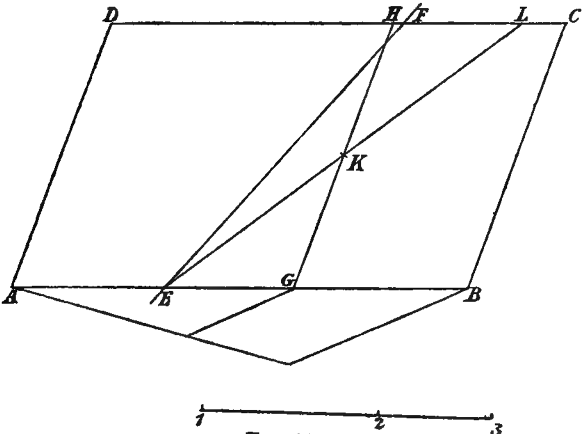


FIG. 111.

Equal in area.—Set off CF equal to AE. A line joining EF divides the parallelogram into equal areas.

Proportionate in area, as the given divided line 1, 3.—Divide AB into the same proportion as 1, 3 in point G. Draw GH parallel to BC, and bisect GH in K. From E, the given point, draw a line through K, meeting the opposite side DC in L. The line EL divides the parallelogram into the required proportionate parts.

(170) To inscribe a rectangle of a given area within a circle of a given radius,—in this case a rectangle of 2″ area and a circle of 1¼″ radius.

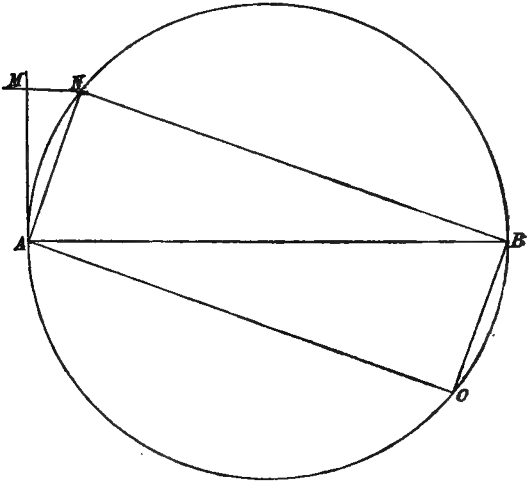


FIG. 112.

Describe a circle with the given radius, and draw a diameter AB. Construct a rectangle ABCD, having an area of one-half the given rectangle. Also draw a rectangle, the radius of the circle being one side, and equal in area to the rectangle ABCD, by Problem 152. At one end of the diameter, as at A, draw a line AM, perpendicular to AB, equal in length to DF. From M draw a line parallel to AB, meeting the circumference in N. Set off BO equal to AN. OANB is the required rectangle.

(171) To draw a parallelogram equal to the area of a given triangle ABC, and having the same perimeter.

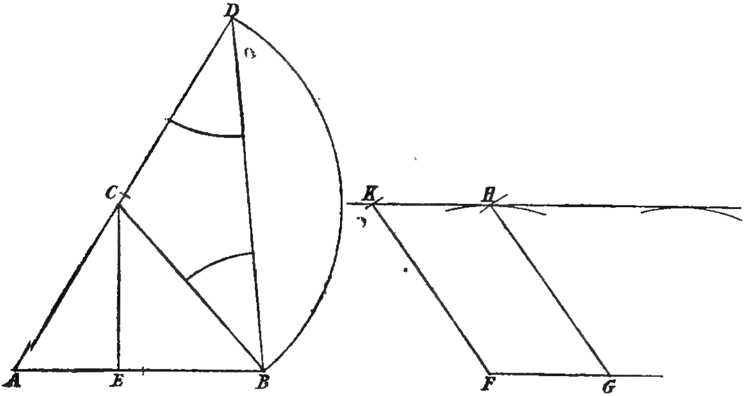


FIG. 113.

Draw two parallel lines at a distance from each other equal to the altitude CE. Set off FG equal to half AB, and CD equal to BC. With G as centre, and radius equal to half AD, cut the line above in H. Draw FK parallel to GH. FGHK is the required parallelogram.

(172) To construct a regular polygon equal in area to a given triangle ACB,—in this case a pentagon.

Divide the side BC of the triangle into as many equal parts as sides in the polygon required. Make the angle CBE equal to one of the angles at the centre of the polygon. (The angles at the centre of a polygon $= \dfrac{360°.}{\text{No. of sides in polygon.}}$) Draw a line from x parallel to AB, meeting BE in point y. The mean proportional BF to AB and By is the radius of the circle circumscribing the polygon. Set off the remaining angles at the centre, as EBG, &c. The arms thus found meet the circumference of the circle in the corners of the polygon required.

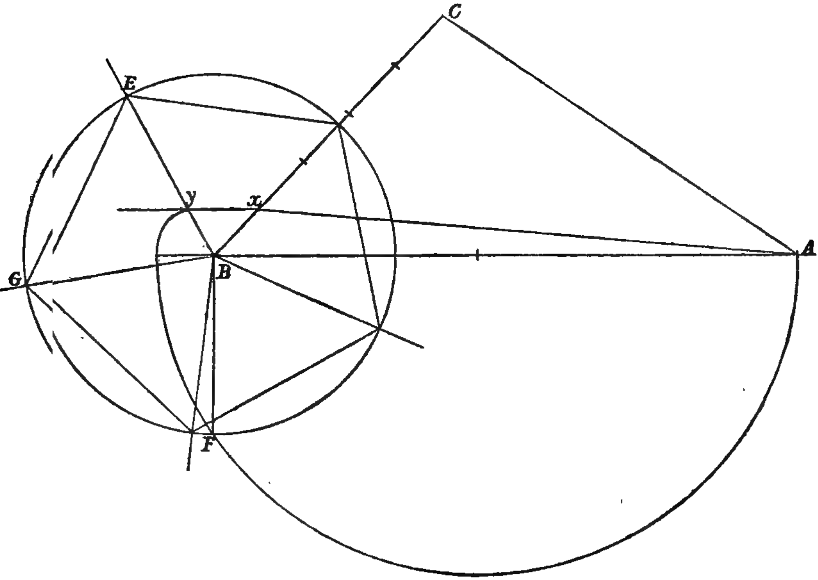


FIG. 114.

(173) To draw a square or a circle equal in area to the difference between two given squares or circles.

Construct a square ABCD on AB as a side, or describe a circle having AB as a diameter. From B mark off BE, equal to the side of the second square or diameter of the second circle. The segment AE is equal to the required side of the square, or the diameter of the required circle. (47 Euc. I.)

Note.—It is obvious that squares or circles may be drawn by this method, equal to the sum of the areas of the given squares or circles, as shown in the figure.

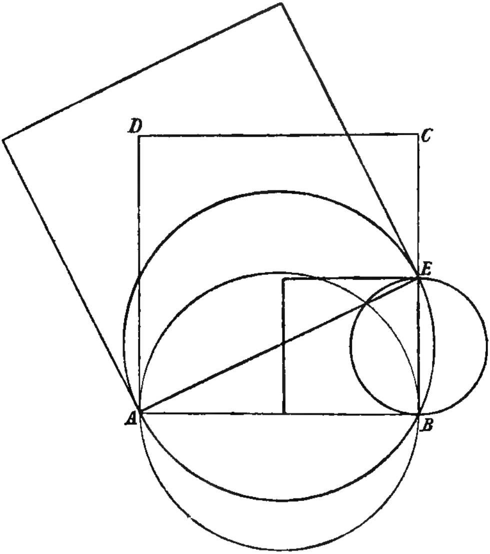


FIG. 115.

(174) To construct a square $\frac{1}{4}$th the area of a given square ABCD.

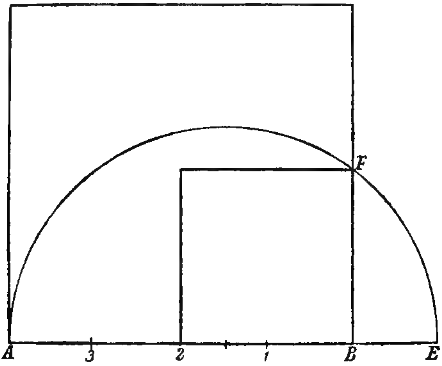


FIG. 116.

Divide the base of the given square into four equal parts, and set off BE equal to one of them. A mean proportional BF to AB and BE is a side of the square required.

(175) To construct a triangle $\frac{1}{3}$ the area of a given triangle ABC.

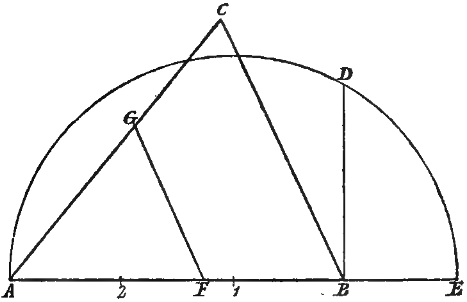


Fig. 117.

Divide the base of the triangle into three equal parts, and set off BE equal to one of these parts. A mean proportional BD to AB and BE is the base of the required triangle. Make AF equal to BD, and draw FG parallel to BC. AGF is the triangle required.

(176) To construct an oblong $\frac{1}{2}$ the area of a given oblong ABCD.

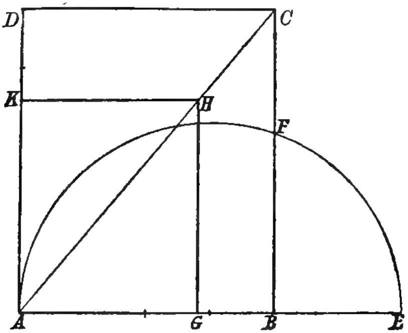


Fig. 118.

Bisect AB, and set off BE equal to half AB. A mean proportional BF to AB and BE is the base of the oblong required. Make AG equal to BF, and draw GH at right angles to AB, meeting the diagonal of the oblong in H. Draw HK parallel to AB. AGHK is the required oblong.

(177) To divide a circle into any number of equal parts, equal in area and periphery.

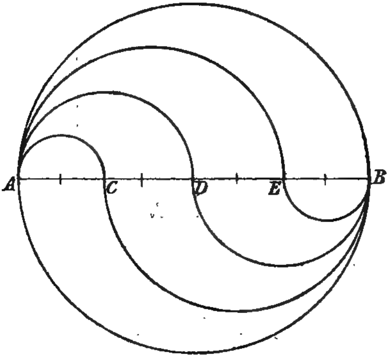


FIG. 119.

Draw a diameter AB, and divide AB into the required number of equal parts,—in this case four. Semicircles described on AC, AD, AE and BE, BD and BC as diameters, divide the circle as required.

(178) To divide a circle into equal areas by concentric circles.

Draw a radius AB, and divide the radius into the required number of equal parts,—in this case three. Describe a semicircle on AB, and at points 1 and 2 draw lines perpendicular to AB, meeting the semicircle in points 3 and 4. With A as centre, and radii A3 and A4, describe circles. These circles divide the given circle into the areas required.

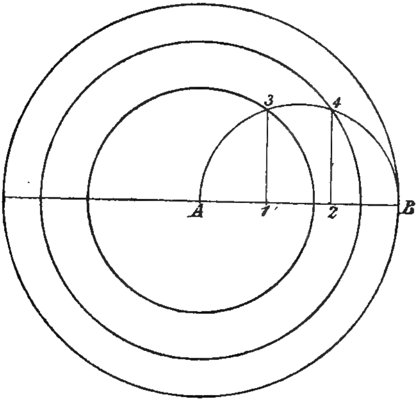


FIG. 120.

(179) To construct an equilateral triangle which has one angle at B on the given line OB, and the remaining angles on OA and OC respectively.

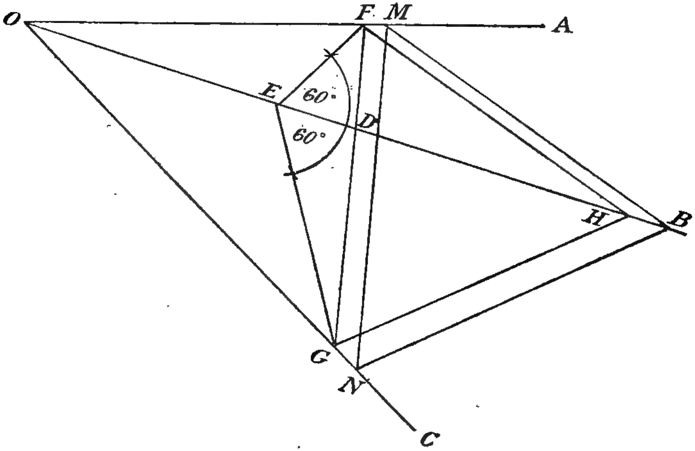


FIG. 121.

Take any point E on OB. Make the angles DEF and DEG each equal to 60°. On GF construct an equilateral triangle, the third corner of which is on the line drawn from O to B. Draw BM parallel to FH and BN parallel to GH. Join MN. The triangle MBN is the equilateral triangle required.

(180) P is a given point on a given line PM. Draw two lines through P making equal angles with PM and meeting a second given line CM in points equidistant from a given point C in it.

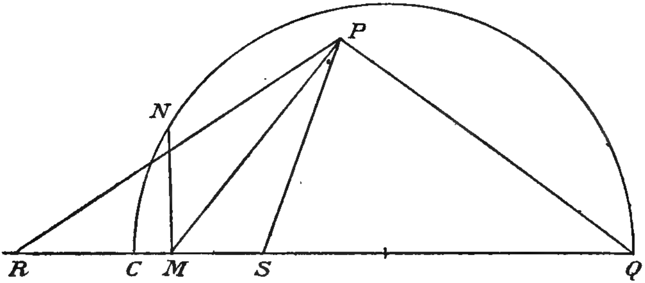


FIG. 122.

From P draw PQ at right angles to PM. Find a mean proportional MN between CM and MQ. Set off the length MN from C in points R and S. The lines PR and PS make equal angles with PM.

(181) To divide a given line A into two parts, such that the sum of the squares upon them shall be equal to the square on the given line BE.

On line BE describe a semicircle; also on BE as a chord describe the segment of a circle containing 45°. From point B set off line A so that BC equals A. The line BC intersects the semicircle in D. Join DE. Set off the length of DE from A in point P, which is the required solution.

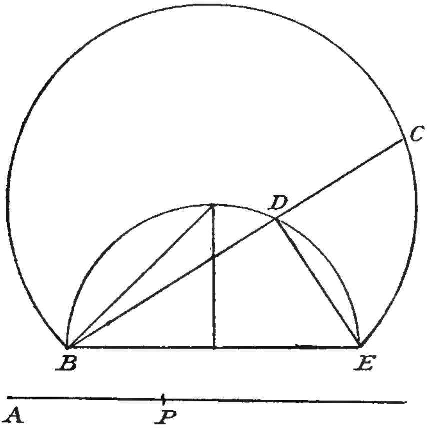


FIG. 123.

(182) Through a given point P draw two lines cutting the two given parallel lines MN OR in such a way that the included area is 2 square inches. (See Fig. 124, p. 98.)

From P draw any line cutting MN and OR in points A and B. The oblong of which AB and AH are alternate sides is equal to two square inches.

Draw HC parallel to AB, intersecting the line MN in point D. The parallelogram ABCD equals 2 square inches.

Bisect CD in F, and draw from P a line through F intersecting the two given lines in G and E. The figure ABEG is the one required, and 2 square inches in area.

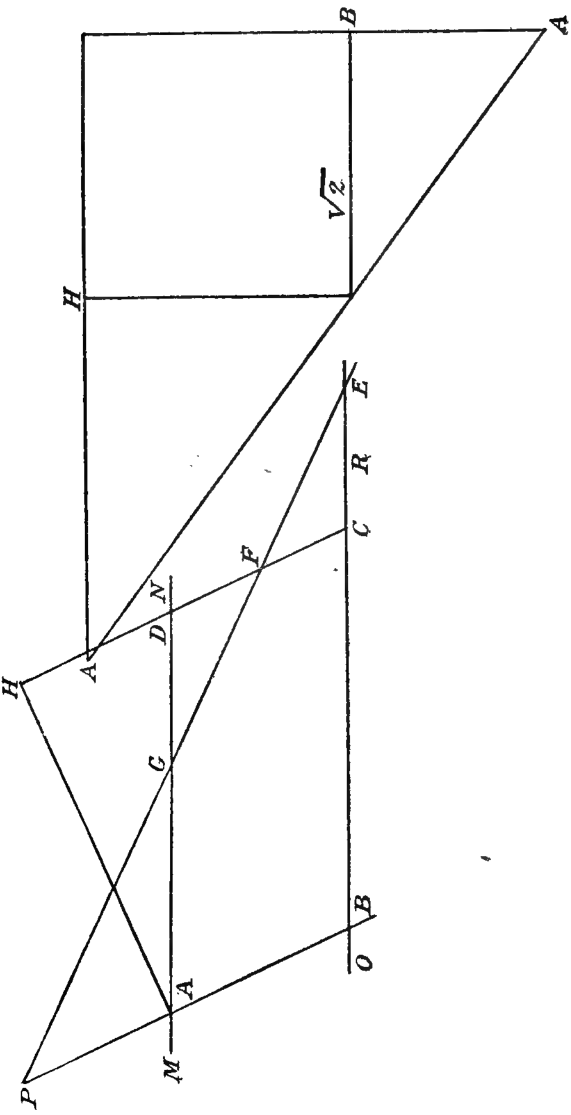


FIG. 124.

(183) To construct a triangle having a base $1\frac{3}{4}''$, a perimeter of $5''$, and an area of $1\frac{1}{8}$ square inches.

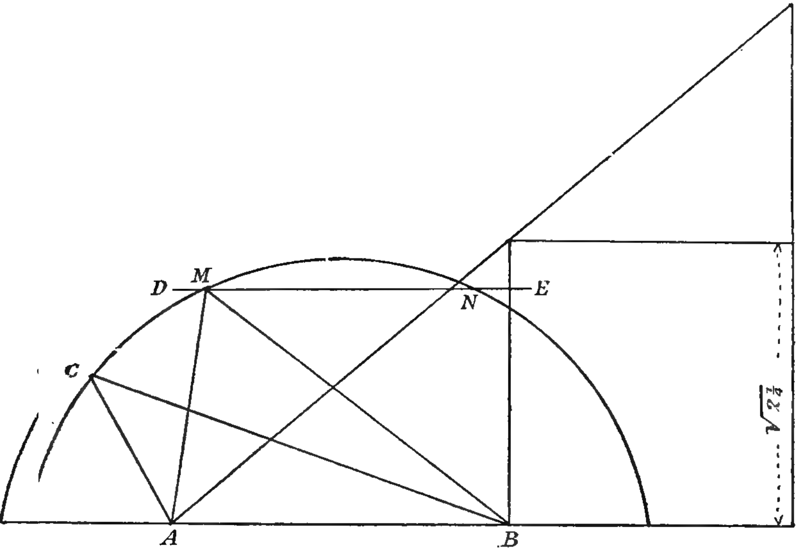


FIG. 125.

Draw a line and mark off the base AB, $1\frac{3}{4}''$. Consider these points A and B as the foci of an ellipse such that any triangle on AB as base, and having its apex C in the curve of the ellipse, shall be equal to the perimeter of the triangle. Construct on AB an oblong equal to twice the area required. The side opposite AB is shown as DE. This line intersects the curve of the ellipse in two points M and N. The triangle ABM is $1\frac{1}{8}$ square inches. Also the triangle ABN. Either of these triangles fulfil the conditions.

(184) Between the given converging lines AB, CD produced if necessary, place a line parallel to EF, in such a position as to form a four-sided figure with an area of 2 square inches.

Produce the given lines to meet in point G. Find the side of a square FH, equal in area to the triangle EFG. Also the side of a square FK, equal to the sum of the square on FH and

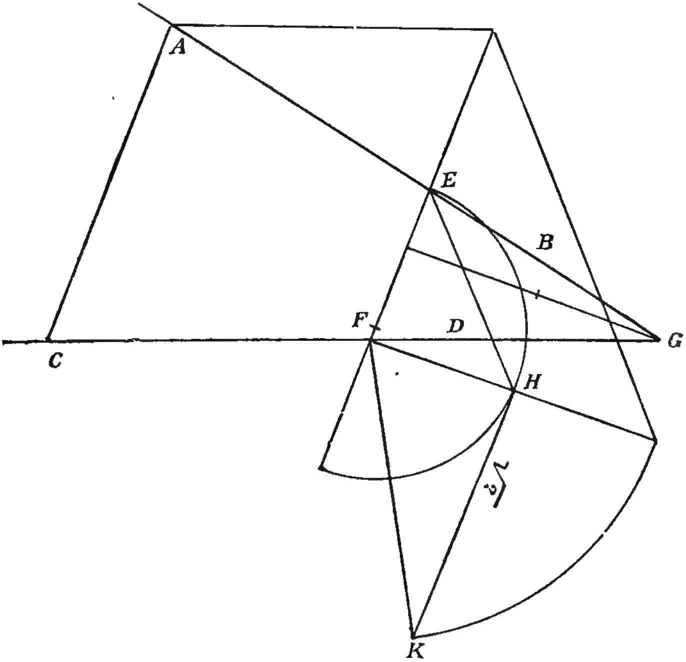


Fig. 126.

2 square inches. A triangle ACG is required similar to the triangle EFG, and equal in area to the square on FK, by Problem 162. The area of the four-sided figure ACEF is 2 square inches.

(185) Draw from A a straight line cutting the given straight lines ABCDEFG, so that the sum of the triangles above it may be equal to the sum of those below.

Join BD and DF. Draw C*c* parallel to BD and E*e* parallel to DF. Join *ce*, and draw D*d* parallel to it. Join A*d*, and draw *ca* parallel to it. A*a* is the line required.

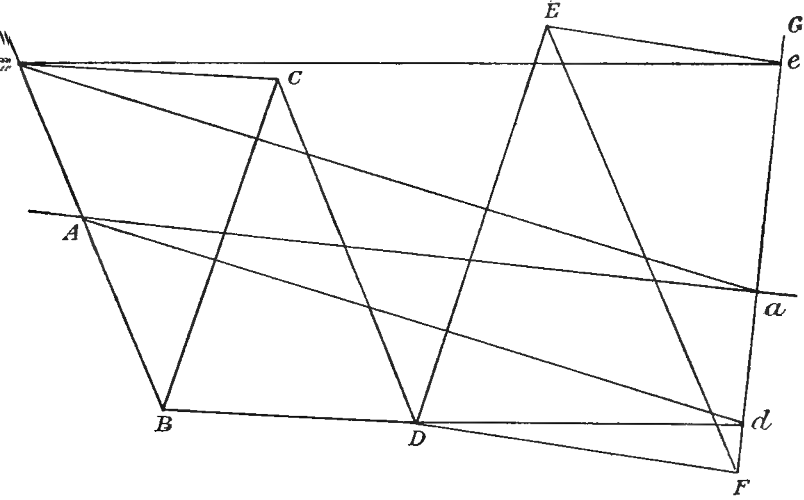


FIG. 127.

(186) To draw the curve of an ellipse, having its major and minor axes AB and CD given, by means of intersecting arcs.

The major and minor axes of an ellipse bisect each other at right angles in point O, the centre of the ellipse. With C as centre, and radius AO, describe an arc cutting AB in F^1 and F^2. These points are the foci of the ellipse. Divide OF^1 into any number of parts decreasing in length towards F^1. With the foci alternately as centres, describe arcs with radii A1, A2, &c., and B^1, B^2, &c., intersecting each other in points which are in the curve of the ellipse. Thus, with A1 as radius, and the foci as centres, describe arcs above and below AB; with B1 as radius, and the foci as centres, also describe arcs; the arcs intersect in points

E, G, H, K, which are in the curve of the ellipse. Through the points thus obtained draw freehand the curve of the ellipse required.

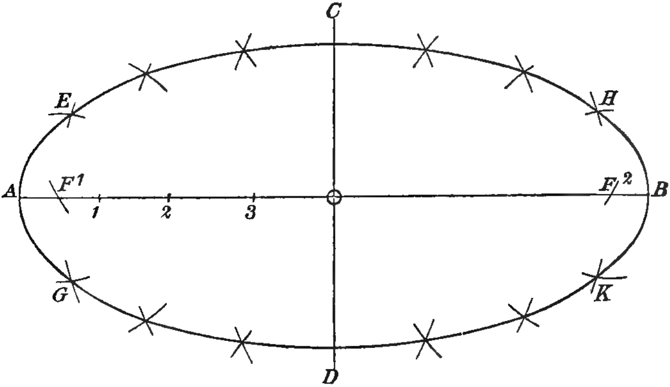


FIG. 128.

(187) To draw the curve of an ellipse, when two conjugate diameters AB and CD are given.

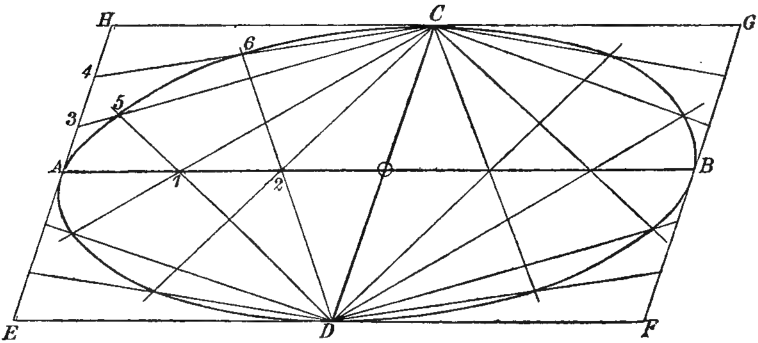


FIG. 129.

Diameters of an ellipse bisect each other in the centre of the ellipse.

Enclose the diameters by a parallelogram, the sides being parallel to AB and CD. Divide AH into any number of equal parts, as 3, 4; also divide AO into the same number of equal parts, as 1, 2. Draw lines from 3 and 4 to C; also draw lines from D through points 1 and 2, meeting the lines C4 and C3 in 6 and 5, which are points in the curve of the ellipse. Any number of points in the curve may be thus obtained. Draw the curve freehand through the points.

Note.—By similar construction an ellipse may be placed within or about a rhombus, a rhomboid, or an oblong.

(188) To draw the curve of an ellipse by means of a paper trammel.

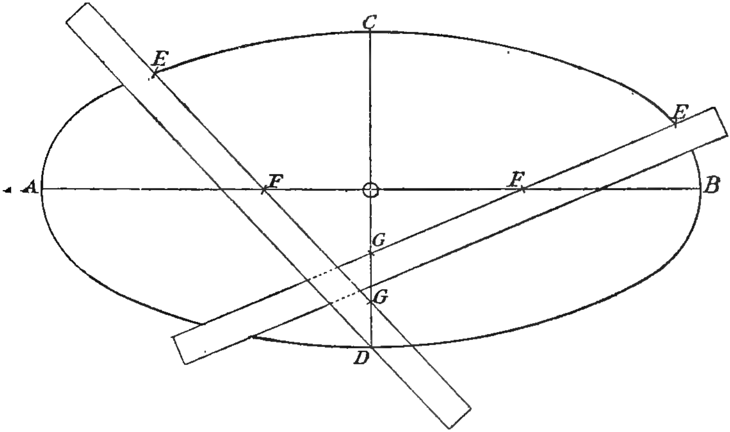


FIG. 130.

On a slip of paper as the trammel, make EF = CO, and EG = AO. By keeping the points FG always on the diameters of the ellipse, or the diameters produced, point E will trace the curve. By marking any number of points at E as you move the trammel, points are obtained in the curve of the ellipse required.

(189) To describe an ellipse by means of string, the transverse and conjugate diameters being given.

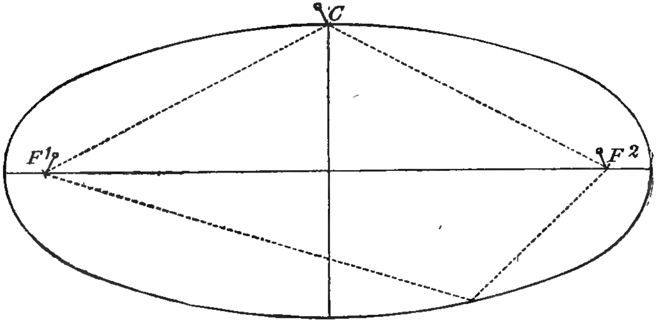


FIG. 131.

Find the foci of the ellipse. Insert needles or pins in point C and each focus. Tie a piece of thread tightly around the three pins. Take out the pin at C and place the point of your pencil inside the string. By moving the pencil and at the same time keeping the string tight, the curve of an ellipse will be produced.

(190) Given the curve of an ellipse to find the major

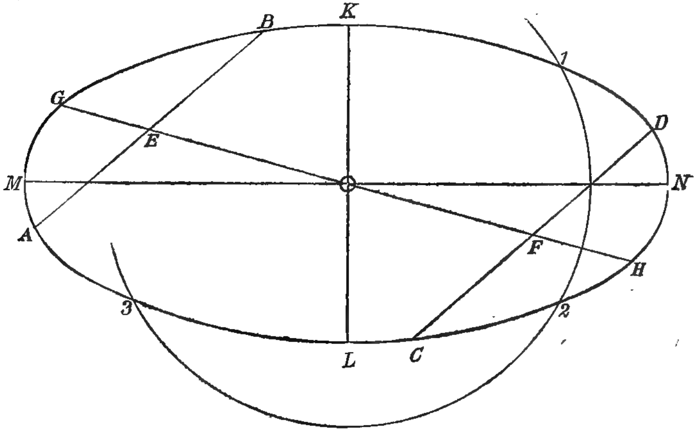


FIG. 132.

and minor axes, also the centre of the ellipse.

Draw any two parallel chords AB and CD. Bisect these chords in E and F. Draw a line through E and F, meeting the curve of the ellipse in points G and H. GH is a conjugate diameter. Bisect GH in O, the centre of the ellipse. With O as centre describe an arc cutting the curve of the ellipse in points 1, 2 and 3. Through O draw lines KL and MN parallel to lines joining 1, 2 and 2, 3. These lines are the axes required.

(191) At point A in the curve of an ellipse, to draw a normal or perpendicular to the curve; also at point B a tangent.

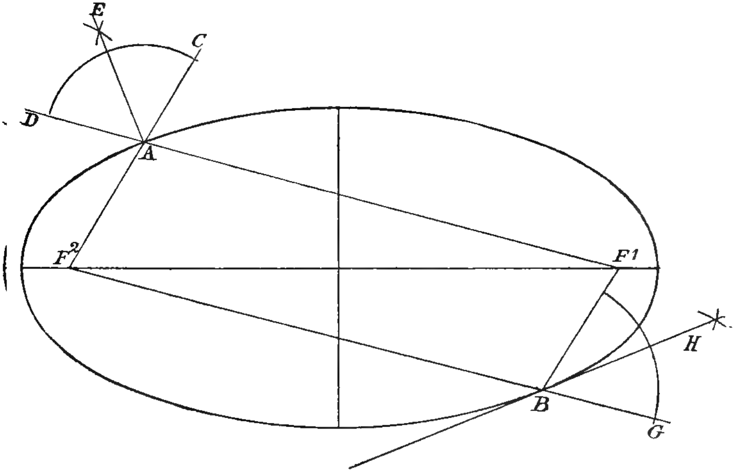


FIG. 133.

Find the diameters of the ellipse and the foci. Draw lines from the foci through point A; bisect the angle DAC by a line AE, the normal required. Draw lines from the foci through point B; bisect the angle GBF1 by the line BH, the tangent required.

(192) To draw a tangent to an ellipse from a point A outside the curve.

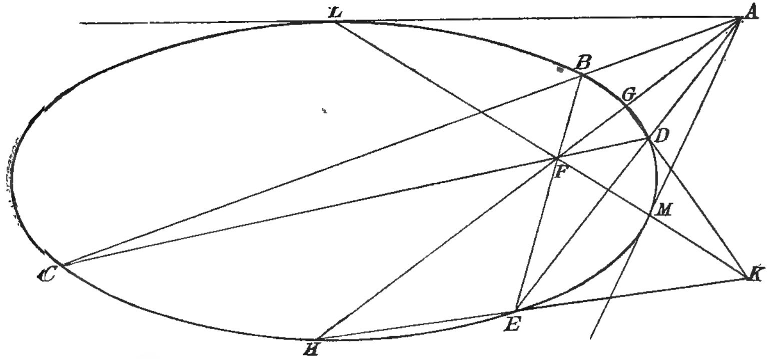


FIG. 134.

From A draw any two lines across the ellipse, intersecting the curve in points B, C, D and E. Draw the lines BE and CD meeting in F, and from A a line through F meeting the curve in G and H. Draw a line from G through D, and a line from H through E, meeting in K. A line drawn from K through point F cuts the curve in points L and M, the points of contact. Lines drawn from A through L and M are tangents to the curve.

Note.—This method of drawing tangents applies to all conics, and may therefore be used for the circle, hyperbola, and parabola.

(193) To construct an oval or egg-shaped figure, the width AB being given.

Bisect AB by a line CD at right angles, cutting AB in point E. From E, with radius EA, describe a circle cutting CD in F. From A and B draw lines through F. With A and B as centres, and radius AB, describe arcs cutting the lines AF and BF produced in points G and H. From F describe the arc GH, completing the oval.

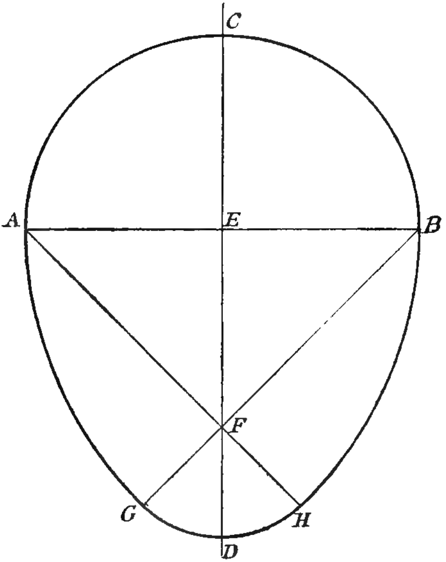


FIG. 135.

(194) If a line have its extremities in two lines, AB, BC at right angles to each other, any point G in the line BC will lie in an ellipse, of which BG and BD would be the lengths of the semi-axes.

Draw AB and BC perpendicular to each other and equal in length. Divide BC into any number of parts, 1, 2, 3, &c., decreasing in length towards C. From these points as centres, and radius BC, cut AB in points 1′, 2′, 3′, &c. Join points 6, 1′; 5, 2′; 4, 3′, &c. From 1, 2, 3, &c. on BC, with CG as radius, cut off on each line 1, 0; 2, 0; 3, 0, &c. Or from 1, 2, 3, &c. on AB, with BG as radius, set off on each line 1′, 0; 2′, 0; 3′, 0, &c. Through points 0 draw the required curve, terminating in G and D. (See also Problem 188.)

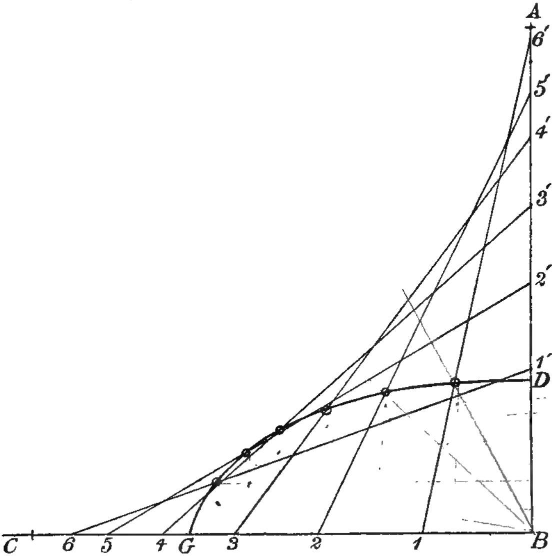


FIG. 136.

(195) To determine points in a parabola, the focus F and the director AB being given.

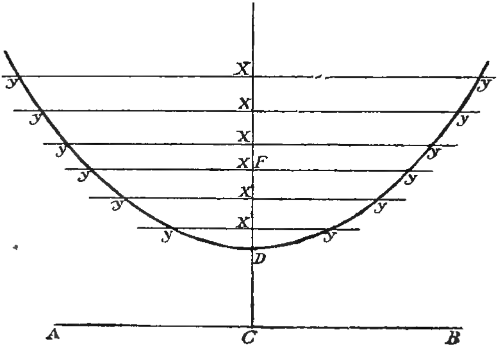


FIG. 137.

The line drawn through F the focus, at right angles to AB the director, is the axis of the parabola. The point D bisecting FC is the vertex of the curve. Draw any number of parallel lines through points X at right angles to the axis. With the focus as centre, and radius XC, cut the lines passing through X in points *y* on each side of the axis. These points are in the curve of the parabola.

Note.—The drawing of a parabola is useful for the solution of problems in Graphic Arithmetic.

(196) To determine points in a parabola, its ordinate AB and its abscissa BC being given; also to draw a normal and a tangent to the curve from point E.

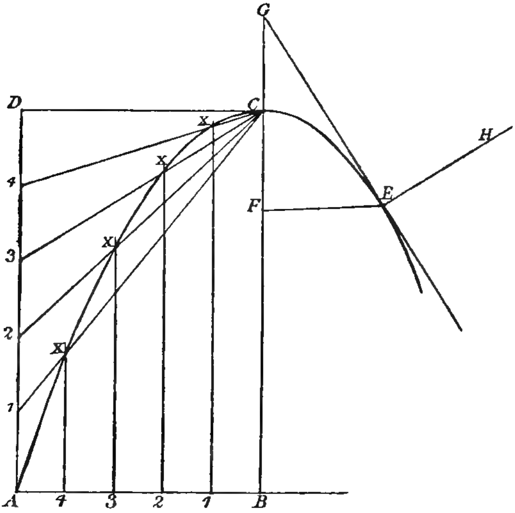


Fig. 138.

Draw AB and BC at right angles to each other, and complete the parallelogram ABCD. Divide AB into any number of equal parts, and AD into the same number, as 1, 2, 3, &c. From the points on AB draw lines parallel to BC, and from the points on AD draw lines to C. These lines intersect each other in points X, which are in the curve of the parabola.

Draw the line EF parallel to AB, produce BC, and make CG equal to CF. Draw a line from G through point E. This is the tangent required. The line EH perpendicular to the tangent is the normal required.

(197) To determine points in a hyperbola, its diameter AB, abscissa BC, and ordinate CD being given.

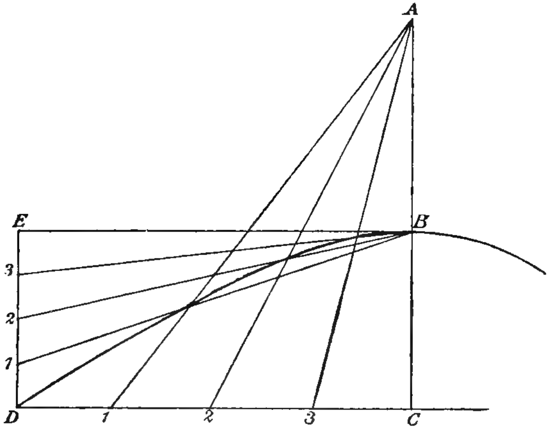


FIG. 139.

Draw BE parallel and equal to CD. Join DE. Divide CD and DE into the same number of equal parts, numbering from D. Draw lines to B from points 1, 2, 3, &c. on DE, and from A to points 1, 2, 3, &c. on DC. The lines intersecting in points which are in the curve of the hyperbola, half of which is shown.

(198) To describe a continuous curve of circular arcs of 60°, with radii of 1, 2, 3, 4, 5 and 6 quarter-inches successively.

Draw any line AB equal to $\frac{1}{4}''$, and from A, with radius AB, describe an arc; and make the angle BAC 60°. Produce CA and make CD equal to $\frac{1}{2}''$. With D as centre, and radius CD, describe an arc, and make the angle DCE 60°. Proceed with the others in the same way, adding $\frac{1}{4}''$ inwardly to each of the last preceding radii.

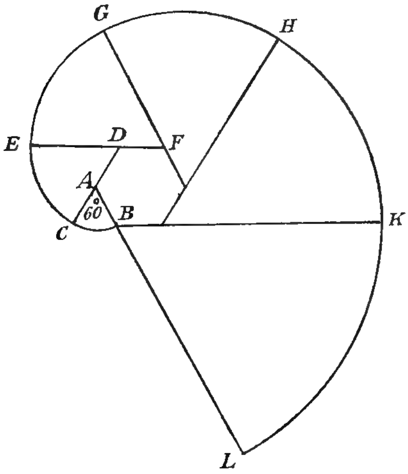


FIG. 140.

(199) To construct the involute of a given circle A.

Divide the circumference of the given circle into any number of equal parts, as six, and draw the radii. Draw tangents to the circle at the six points, and produce the tangents in one and the same direction, that from point 1 being equal in length to $\frac{1}{6}$th of the circumference, that from point 2 equal to $\frac{1}{3}$rd, &c., and the last from point 6 equal to the circumference. Draw the curve freehand through the outer extremities of these tangents, which will be the required involute.

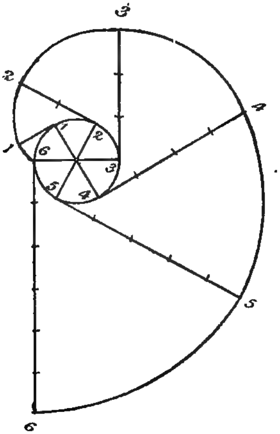


FIG. 141.

Note.—The greater the number of points taken in the circumference of the circle the more accurate the involute.

CYCLOIDAL CURVES.

If a circle rolls along a line, and is always in the same plane, a point moving with the circle describes a cycloidal curve. The director is the line along which the circle moves. The generator is the point connected with the circle.

If the director is a straight line, a point on the circumference of the circle traces a cycloid.

If the point is within or outside the circumference, a trochoid is traced.

If the director is a circle, the curves described by a point in the circumference or not, and as the circle rolls inside or outside the director, are the epicycloid, hypocycloid, epitrochoid, and hypotrochoid.

(1) To determine points in a cycloid, when the director AB and the generating circle O are given.

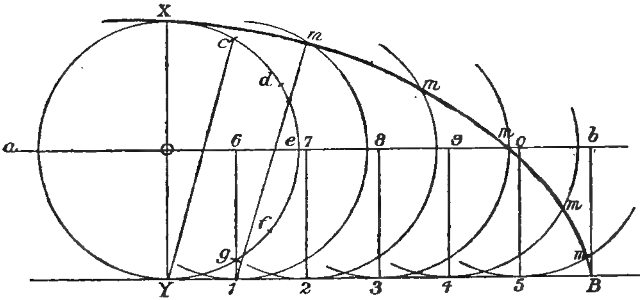


Fig. 1.

Through O, the centre of the circle, draw *ab* parallel to AB, the path in which the centre O will move. Divide the circumference of the generating circle into any number of equal parts, as *c*, *d*, *e*, *f*, *g*. If X be the generating point, it will be at A at the commencement, and at the end of the revolution at B. On each side of Y set off the lengths 1, 2, 3, 4, 5, equal in size and number to the divisions in the circle. At these points draw perpendiculars to AB meeting O*b* in 6, 7, 8, 9, 0. From each of these points as centres describe arcs with OY as radius, and from each point 1, 2, 3, &c. in BY, set off on these arcs the chords Y*c*, Y*d*, &c. The cycloid is drawn through the points *m*. In the figure only half the curve is shown, from B to X; the other half, from A to X, is the exact counterpart of the first.

(2) To draw the trochoid.

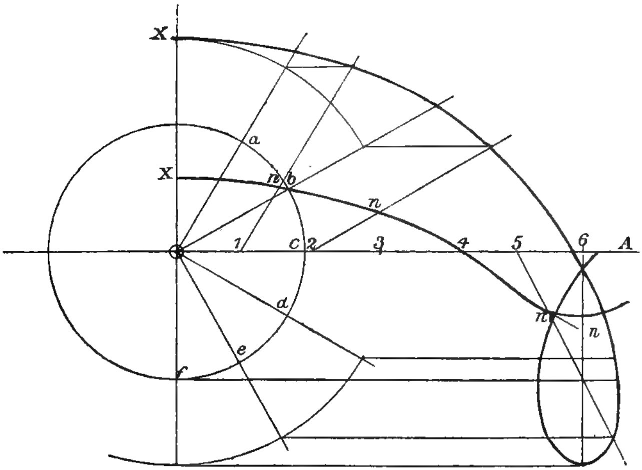


FIG. 2.

In this case the generating point is at X within the circle. Draw the radii O*a*, O*b*, O*c*, &c. of the circle through the points of division in the circumference, and draw lines parallel to these radii through points 1, 2, 3, &c. in OA. By making each of these parallels equal to OX, we obtain points *n* through which to draw the curve of the trochoid. In the figure half the curve is shown. If point X is outside the circumference, the curve will have a loop in it, formed by the motion of the circle along the director.

(3) To draw the epicycloid and hypocycloid, the director AB and the generator C being given.

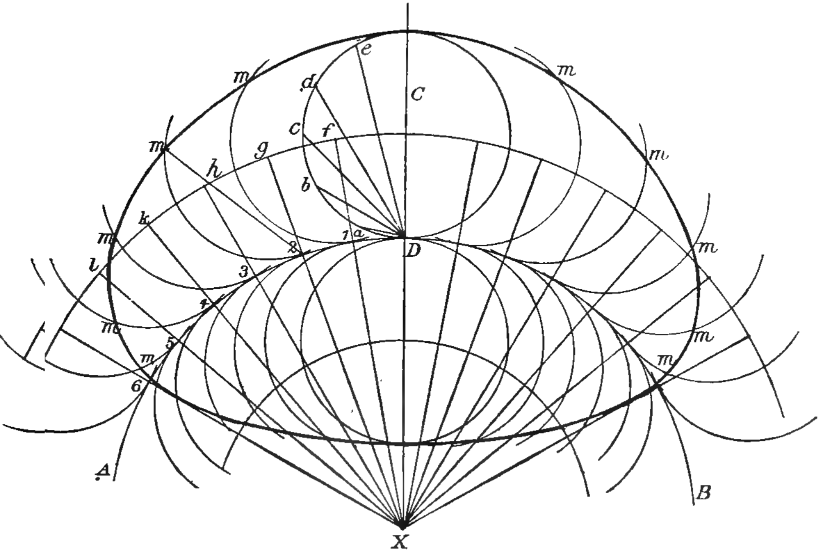


FIG. 3.

Divide the generating circle into any number of equal parts, *a*, *b*, *c*, &c., and set off these lengths from D on the directing circle in points 1, 2, 3, &c. From X draw lines through 1, 2, 3, &c., cutting the circle of centres in *f*, *g*, *h*, &c. From each of these points describe circles similar to the generating circle, and set off from points 1, 2, 3, &c. the chords D*a*, D*b*, D*c*, &c., on the circles resting on them; and through the points *m* the curve of the epicycloid is drawn. If the generating circle rolls inside instead of outside the directing circle, the curve traced is the hypocycloid. It is constructed in precisely the same manner as the epicycloid, excepting the measurements are inside instead of outside the directing circle.

Note.—The property of cycloidal curves is important in the application of gearing. The straight line and the ellipse may be considered as variations of cycloidal curves.

(4) To draw a chonchoid, X the pole and AB a straight line being given.

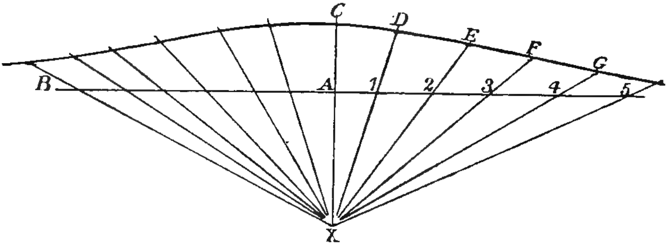


FIG. 4.

Through X draw any number of lines, cutting AB in points 1, 2, 3, &c. AC is given. Make 1D, 2E, 3F, &c. equal to AC; the curve drawn through these points is the chonchoid required.

If point C is between X and AB, the same construction gives the inferior chonchoid.

If AC is greater than AX, the inferior chonchoid has a loop in it. In every case the straight line AB is the asymptote to the curve.

(5) To draw the cissoid.

Describe a circle on AB, and draw any number of lines at pleasure from B to cut CD, which is perpendicular to AB. Make B*l*, B*m*, &c. equal to 1*a*, 2*b*, &c., and draw the curve of the cissoid through the points.

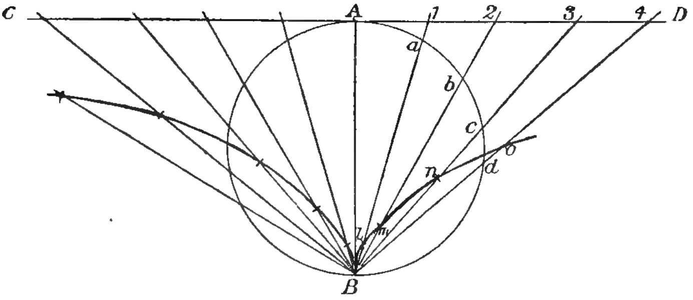


FIG. 5.

Note.—If a chain be suspended at two points in a vertical plane, the curve so formed is a catenary, which is not a geometrical curve and cannot be constructed.

(6) A railway train is running in a straight line at 12 miles an hour. The door of one of the carriages swings open, so that each point of the door describes with uniform velocity a quarter of a circle about the hinge, and immediately closes again at the same rate, the whole time of opening and closing being half a second. The width of the door is 27″. Draw the curve traced by a point on the edge of the door. Scale ½″ to a foot.

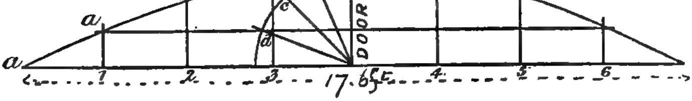


FIG. 6.

First find the distance per second the train travels = 17·6 feet. The door opens and closes in this distance. Draw a line 17·6 feet long by scale, and at the centre point set up a perpendicular equal to the width of the door, and on it describe a quarter of a circle. Divide this arc into any number of equal parts, and the distance travelled per second into twice the number. Draw lines through *b*, *c* and *d* parallel to 1, 6, to meet the perpendiculars set up at points 1, 2, &c. *a* is the point on the door which traces the curve drawn through the intersections of the straight lines. The curve is a cycloid. (See Problem 1.)

EXAMPLES.

The double accent (″) signifies inches. Questions marked (*) have been set at examinations.

*(1) Draw any two parallel lines, and find a point equidistant from these lines.

(2) Describe a triangle, the sides of which shall be 2·28″, 3·4″, 3·36″.

*(3) Draw a circle with a radius of 1·6″. Take a point 3·7″ from the centre. From this point draw two tangents to the circle.

*(4) On a vertical line AB, 3″ long, construct a triangle having an angle of 40° at A, and 50° at B. (Only one angle need be taken from the protractor.)

*(5) Divide a line 7″ long into six equal parts. On each part as diameter describe a semicircle, placing them alternately above and below the line so as to form a continuous curve.

*(6) Divide a line 2½″ long into four parts, in such a manner that the second shall be twice the length of the first, the third three times the length, and the fourth four times the length.

(7) Make angles of 70°, 115°, 75°, 135°, 150°, without using the protractor.

(8) Construct a right-angled triangle, making the hypotenuse twice the length of the base. Inscribe a square within the triangle.

(9) Draw nine circles of ·52″ radius in three rows, their centres being in lines parallel to each other at 1·12″ apart.

*(10) Draw two straight lines AB, CD, each 3″ long; such that C is 1″ from A, and D $\frac{3}{4}$″ from B. Draw a straight line which would bisect the angle formed by the two given lines if they were produced.

*(11) Draw a sector of 2″ radius, and having an angle of 150°. Within this sector inscribe a circle.

*(12) A trapezium has two sides, each 1·5″ long, and the enclosed angle is 80°. The other two sides are each 2·4″ long. In this trapezium inscribe a square.

*(13) Make a triangle whose sides are 2″, $2\frac{1}{7}$″, $2\frac{4}{9}$″, and inscribe a circle within it; also describe a circle about it. What are the radii of these circles?

*(14) Construct an equilateral triangle to contain an area of 3 square inches.

*(15) Construct a regular hexagon on a line AB, $\frac{5}{6}$″ long, as one of its sides. On each side of this hexagon construct another similar to it.

*(16) With a radius of 1·25″ describe a circle, and from a point P, distant 2·75″ from the centre, draw a straight line PBC to cut the circle so that BC may be equal to 2″.

*(17) Construct a square equal in area to the sum of the areas of three squares whose sides are 1″, 1·5″, and 2″ respectively.

*(18) Construct a pentagon with a perimeter of $10\frac{1}{2}$″, and transform it into a square of equal area.

(19) About a circle of 2″ diameter circumscribe an octagon.

*(20) About a circle of $1\frac{1}{2}$″ diameter place a triangle, having two of its angles 30° and 105°. On one side of the triangle as base construct a rhomboid equal in area to the triangle, and having one of the angles at its base 75°.

(21) Draw a rhomboid of which the longer sides are 3″ long and the shorter 2″, and the acute angles 50°. Draw an equilateral triangle equal in area to this rhomboid.

*(22) Inscribe a regular pentagon within a circle of 3″ diameter. Reduce the pentagon to a triangle, and the triangle to an equal octagon.

*(23) Draw a straight line $2\frac{13}{17}''$ long. On this construct a square. Inscribe a regular octagon in the square.

(24) Draw a straight line 3·54″ long, and divide it in extreme and mean ratio.

*(25) On a straight line 2″ long describe isosceles triangles having vertical angles of 100°, 120° and 150°.

*(26) Make a square equal in area to the sum of the three triangles in the last question.

*(27) Describe a regular pentagon whose side is $1\frac{1}{2}''$ long. Inscribe a square within the pentagon.

*(28) Describe a circle of 1·75″ radius, and divide the circle into five equal areas by concentric annuli.

*(29) Draw straight lines whose lengths are $\sqrt{3}''$, $\sqrt{\frac{1}{3}}$, $\sqrt{2}$, $\frac{2}{\sqrt{3}}'$, respectively.

(30) Draw two circles having their centres 3″ apart, and their radii $1\frac{1}{2}''$ and 1″ respectively. Draw the four common tangents to these circles.

*(31) Divide a straight line 3″ long into two parts whose ratio is $2 : 3\frac{1}{2}$. On each side of each part describe an equilateral triangle. In each of the two rhombi obtained inscribe a circle.

(32) Describe a square, each side of which is 1·3″. Describe an equilateral triangle about it.

*(33) Draw a straight line 2″ long, and on it describe a segment of a circle containing an angle of 100°.

*(34) On a straight line 1·26″ long describe a segment of a circle containing an angle of 70°. Inscribe a square in this segment.

*(35) Draw a cinquefoil of adjacent semicircles of $\frac{1}{2}''$ radius.

*(36) Show how a tangent can be drawn from an external point to a given circle without using the centre of the circle.

*(37) On a straight line 1·75″ long construct a regular heptagon and an equilateral triangle on the same side of the line. Reduce the space between the outside of the triangle and the inside of the heptagon to a triangle of equal area.

*(38) The diagonal of an oblong is 3″. One side of the oblong makes an angle of 30° with one end of the diagonal. Construct the oblong and draw an equilateral triangle equal in area.

(39) Describe a circle of $1\frac{1}{4}''$ radius. Divide this circle into five equal sectors.

*(40) Within a circle of 3″ diameter inscribe an irregular polygon, having angles at the centre equal to 45°, 60°, 120°, 30°, and 105° respectively.

*(41) About a circle of $2\frac{1}{2}''$ diameter construct a regular heptagon.

(42) Draw a circle of 2″ radius, and in it place four equal circles touching it and each other.

*(43) In a circle of 5″ diameter place a regular octagon. Divide this into isosceles triangles, and in each of these place a square having one angle in the centre of each side of the octagon.

*(44) Determine by construction the side of a square of 8″ area. Inscribe a regular octagon in the square.

*(45) Draw two lines including an angle of 75°. Divide this angle by construction into four equal parts. In each of the four angles inscribe a circle of ·9″ diameter.

*(46) Construct a triangle which shall have $\frac{2}{3}$ the area contained by a square of $2\frac{1}{2}''$ side.

(47) About a circle of $\frac{3}{4}''$ radius construct a triangle having its angles 45°, 60°, and 75°.

*(48) Construct an equilateral triangle of 4 square inches area.

*(49) Draw the circles inscribed in and circumscribing a triangle of 3″, $2\frac{1}{2}''$, and 2″ sides.

*(50) Construct a triangle having a perimeter of $3\frac{1}{2}''$, and two of its angles 45° and 60°.

*(51) Construct a triangle having its sides as 2, 3, 4, but inscribed in a circle of 1·5″ radius.

*(52) Construct a triangle, its sides being in the ratio of 2·5, 3, 3·75, and their sum equal 5″

(53) Construct a regular pentagon having a line 3″ long as one diagonal.

*(54) Construct a regular heptagon of 1½″ side, and in it place seven semicircles, their diameters adjacent and each arc touching one side of the circumscribing figure.

*(55) Construct a triangle with a base of 2″ and an opposite angle of 76°; and on a base 2½″ another triangle of twice the area.

(56) Within a rectangle of 4″ and 2¼″ sides inscribe an ellipse which shall touch the centre of each side of the rectangle.

*(57) Two diameters of an ellipse make 60° with each other and are equal in length. Draw the curve of the ellipse of which these are conjugate diameters.

*(58) Plot an angle of 83° from the protractor. Divide the angle into four equal parts, and in each part inscribe a circle of 1″ diameter.

*(59) Divide a line 3·18″ long in the ratio of 5·5 to 9·7.

*(60) Draw an irregular five-sided figure, ABCDE. AB is 4·5″ long, BC is 2·6″ long. A line from B to D is 4·7″, and one from C to E is 2·75″ long. Angle BAE is 46°, AED is 133°, and ABC 85°. Draw a similar figure having half the area of the first.

*(61) A point starting from the intersection of two lines at right angles moves so that the ratio of its distances from the two lines is always as 3 : 4. Trace the line made from its starting-point for about 3″.

(62) Draw two lines cutting each other at an angle of 55°, and describe all the circles of 2″ diameter which will touch both.

*(63) ABCDEF is a regular hexagon. G is the middle point of CD, and AG equals 2·25″. Draw the hexagon.

*(64) The sides of a triangle are 2″, 2¼″, and 2½″ respectively. Trisect the triangle by straight lines drawn from the middle point of the longest side.

(65) Inscribe a trefoil of adjacent semicircles in a circle of $1\frac{1}{2}''$ radius. Also a cuspidate trefoil in the same circle.

*(66) Describe an isosceles triangle having each of the equal sides 2″ long and the vertical angle half either of the base angles. What is the magnitude of the vertical angle?

*(67) A triangle on a base of 2″ has an area of 3 square inches. What is the altitude?

(68) ABC is any triangle. On the side BC construct an equal isosceles triangle.

(69) Describe an equilateral triangle about a given circle.

*(70) Describe a circle of 2″ radius. Suppose this to be the face of a watch, and show accurately the position of the two hands at 25 minutes past 8.

(71) Two circles of radii 2″ and 1″ have their centres 4″ apart. Describe a circle of 1·5″ radius which shall touch both.

*(72) ABCD is a trapezium. The angle at $A = 120°$; AB is 2″, AD is 1″, BC is 2″, DC is $\frac{3}{4}''$. Bisect this trapezium by a straight line drawn from A. Make a square equal to half the trapezium.

*(73) ABC is a right-angled triangle, having the right angle at A. Construct a square which shall be equal in area to the sum of the squares described on BC, CA and AB. Also draw a square which shall be equal in area to the difference of the squares described on AB and AC.

(74) Describe by the method of intersecting arcs an ellipse having its semi-minor axis 1·54″ and its semi-major axis 2·86″.

(75) The hypotenuse of a right-angled triangle is 2·75″, and the other two sides are to each other in the ratio of 3 : 5. Construct the triangle.

*(76) Draw two straight lines 2″ apart and parallel to each other. Take a point P between them, and distant ·5″ from one of them. Describe a circle that shall touch the two straight lines and pass through the point P.

(77) Describe a circle of 1·5″ radius, and in it inscribe three equal circles, each touching the other two and the original circle.

*(78) Draw a straight line AB, and take a point P 1″ above it. Draw a curve every point of which shall be equally distant from AB and the point P. What is the name of the curve?

(79) Draw a straight line AA, 6″ long, and take a point P 2·25″ above it; from the point P draw all the lines which make angles of 38°, 56° and 74°, with the line AA.

*(80) Construct four concentric, similarly situated hexagons 0·3″ apart; the side of the largest to be 2·25″.

(81) Between two concentric arcs of circles of 2·4″ and 3·7″ radius describe four circles touching the given circles and each other successively.

(82) ABC is a triangle, and D a point in AC. Construct an isosceles triangle standing on AD as base, and equal in area to the given triangle ABC.

(83) Inscribe four equal circles in a regular octagon of 2″ side.

*(84) Draw a third proportional to two straight lines whose lengths are $1\frac{1}{3}''$ and $1\frac{1}{7}''$. What is its length?

*(85) Describe three circles of radii 1″, 2″, and $2\frac{1}{2}''$, touching each other.

*(86) Draw a straight line 4·37″ long. Divide it into five equal parts, and through the points of division draw parallels ·65″ apart.

(87) ABC is a triangle, and D is a point in AB such that AD is $\frac{2}{7}$ AB. Draw a straight line through D which shall bisect the triangle.

(88) With a radius of 2·5″ describe a quadrant of a circle, and in it inscribe a circle. What is the radius of the circle?

*(89) Construct a triangle having its sides 3·25″, 2″, and 2·5″. Divide it into four equal areas by straight lines drawn parallel to the shortest side.

(90) Make a square the area of which is $\frac{5}{8}$ of the area of another square whose diagonal is 2″. What is the length of the side of the latter square?

*(91) Describe a regular octagon having each side 1″ long. Describe another octagon, one-third of the area of the former one.

*(92) ABC is a triangle such that AB is 2″ long, BC $2\frac{1}{2}$″, and CA $2\frac{3}{4}$″. P is a point within the triangle, and AP is $\frac{3}{4}$″. Draw straight lines from P which shall trisect the triangle.

(93) ABC is an isosceles triangle, having AB equal to AC, and BC is 2″ long. Describe a rectangle on BC, the area of which is equal to that of the triangle.

*(94) Construct a square having its sides equal to $\sqrt{3''}$, and in it inscribe four circles, each touching two other circles and one side of the square.

*(95) ABC is a triangle. Find a point P in BC, such that the perpendiculars from it on AB, AC are equal. How would you solve this problem if the directions BA and CA are given, but the point A is inaccessible?

*(96) Describe an ellipse with a paper trammel, having its major axis a line $\sqrt{5''}$ long, and for its minor axis a line $\sqrt{3''}$ long.

(97) Describe a hexagon having each side 1″ long. Remove one of the six equilateral triangles composing it; reduce the remaining figure to an equal square.

*(98) From a point A draw two straight lines containing an angle of 30°, and across them draw another straight line PQ, 2″ long, such that AP : AQ : : 2 : 3.

(99) Describe a circle of 1″ radius. Within the circle inscribe a triangle whose sides are in the proportion of 6 : 19 : 21.

(100) Divide a straight line 6″ long in the proportion of 2 : 3 : 4 : 5. Make a quadrilateral whose sides are equal to these parts respectively, and reduce the quadilateral to a triangle of equal area.

*(101) Two angles of a triangle are 30° and 40° respectively. Construct a similar triangle having a perimeter of 4″.

*(102) Make a triangle equal in area to that constructed by the last question, but having its angles 30°, 60°, and 90°.

*(103) The base of a triangle is 1″, its altitude $1\frac{1}{2}$″, and its vertical angle 30°. Construct it.

*(104) The base of a triangle is 1″, one of its sides is $1\frac{1}{2}$″, and its vertical angle is 30°. Construct it.

(105) Inscribe three circles in an equilateral triangle, each circle touching the two other circles and one side of the triangle.

(106) Inscribe three circles in any given triangle, each circle touching the two others and two sides of the triangle.

(107) Take a straight line 3·56″ long, and divide it in extreme and mean ratio. What are the lengths of the two segments?

(108) About a circle of $2\frac{1}{2}$″ diameter construct a triangle having angles of 30°, 45°, and 105°.

*(109) Construct a square on a vertical line 3″ long as a diagonal. Within the square insert a quatrefoil of equal semicircles with adjacent diameters, the arcs touching two sides of the square.

*(110) Within a square of 2″ side inscribe the largest possible equilateral triangle.

*(111) From any point in the circumference of a circle of $1\frac{1}{2}$″ radius draw a chord which will cut off a segment containing an angle of 30°.

(112) On a given line 2″ long construct an equilateral triangle; also on the same line a scalene triangle of the same area, and having an angle of 20°.

*(113) Within an equilateral triangle inscribe a trefoil of tangential arcs of circles.

*(114) Draw a circle of 1″ diameter. About this circle draw six equal circles touching one another and the given circle.

(115) Inscribe an equilateral triangle within a pentagon of $1\frac{1}{2}$″ sides.

*(116) Within a circle of 3″ diameter inscribe two circles of 1″ and $1\frac{1}{2}$″ diameter. The three circles to be tangential to each other.

*(117) Given a circle and a point outside. Draw a circle to pass through the given point and to enclose the given circle tangentially.

(118) Draw a triangle having one of its angles 52°, and the two sides containing it 1·8″ and 2·6″. Find the centres of the inscribed and circumscribing circles.

*(119) Draw a rectangle 2·2″ long and ·9″ wide. Divide it by lines parallel to the shorter sides into five rectangles, in such a way that the second rectangle shall be twice the area of the first, and each of the others as large again as the one it succeeds.

(120) Within a circle of 3″ diameter place five equal circles equal to and touching each other and the periphery of the larger circle.

*(121) Construct a right-lined polygon of seven sides from the following conditions: AB = 1·5″, BC = 1·8″, CD = 2·1″, DE = 2·4″, EF = 2·28″. FG to be made equal GA. Angle GAB = 120°, ABC = 130°, BCD = 140°, CDE = 130°, DEF = 120°. Reduce this figure to a triangle of equal area having its vertex in E and its base in GA produced.

*(122) Construct an irregular polygon from the given dimensions, and reduce it to a square of equal area. AB $2\frac{1}{2}$″, BC 2″, AD $3\frac{1}{2}$″, AE and DE each $2\frac{1}{2}$″. Angle BAC 27°, DAC 25°.

(123) About a circle of 1″ diameter place four others equal to each other, and each touching two others and the given circle.

*(124) Draw three equilateral triangles having their sides respectively in the ratios of 2, 3, and 5, the least being 1″ in length.

*(125) Construct a parallelogram the adjacent sides of which measure 2·5″ and 1·65″, and the included angle 115°. Construct a square equal in area to the parallelogram.

*(126) Plot an angle of 57° and bisect this angle; again bisect the angles so obtained.

(127) A parallelogram has one side 2·98″ long, and its diagonals are 2·23″ and 4·5″ long. Construct it.

*(128) Upon a straight line 3·5″ long, and upon the same side of it describe two segments of circles containing respectively 145° and 65°. Draw an angle in each segment.

(129) Construct the segment and sector of a circle, each having the same chord, 3·4″, and the same radius, 2·3″. Measure and write down the magnitude of the angle in the segment.

*(130) Determine by construction a third proportional to two given lines, $2\frac{1}{4}''$ and $2\frac{7}{8}''$ long. Find a fourth proportional to the three lines.

*(131) A line AB is 2·7″ long. At A a line AC, 1″ long, makes an angle of 110° with AB. At B a line BD, 2″ long, makes an angle of 130° with AB. From C, with a radius of $2\frac{1}{3}''$, and from D, with a radius of $2\frac{2}{3}''$, describe arcs meeting in E. Reduce this figure to a triangle of equal area and having one of its angles 90°.

(132) Draw a regular hexagon having a perimeter of 9″, and within it draw a second having its sides equidistant from and parallel to the first, but forming a figure of only half the area of the outer hexagon.

*(133) Construct an isosceles triangle of which the base measures 2·35″ and the angle subtended by the base 41°. Measure and write down the length of the sides, and divide one of them into nine equal parts.

*(134) Draw a circle of 5″ diameter. In it place the largest possible octagon; in the octagon the largest possible square; in the square the largest possible circle; and in the circle the largest possible equilateral triangle.

(135) Draw a series of circles, diameters 1″, 1·25″, 1·5″, and 1·75″, touching each other successively, and all touching a straight line.

(136) Show how to find the centre, foci, and diameters of a given ellipse, and draw a tangent at any point in the curve.

*(137) Construct a square containing an area of 4·84 square inches, and to a line 2·6″ long apply a parallelogram of equal area with the square and having one of its angles 65°.

*(138) The base AB of a right-angled triangle is 3·6″ long, and the perpendicular drawn from the right angle at A to the hypotenuse is 2″. Construct the triangle.

*(139) Two points, A and B, are 2″ apart. From each of them draw lines $2\frac{1}{3}$″ long, intersecting each other at right angles.

*(140) Upon a straight line 3″ long construct a square. Bisect the line, and upon one of the halves construct a second square inside the first one. Reduce the space by which the first square exceeds the second to a triangle of equal area.

*(141) Draw two parallel lines $1\frac{1}{2}$″ apart and 2″ long. Between these insert nine other lines parallel to them and dividing the space between them into equal parts. Ink in the lines with thick, thin, and dotted lines alternately.

*(142) Draw a triangle of which two sides measure 3·2″ and 2·6″, and the enclosed angle 108°. Draw an equilateral triangle of equal area.

*(143) Draw a polygon ABCDE, of which the side AB is $1\frac{3}{4}$″ long, BC 2·3″, AE 1·85″, DE $1\frac{1}{2}$″. The angle ABC is 111°, BAE 113°, AED $122\frac{1}{2}$°. Measure and write down the length of the remaining side and angles, and reduce the polygon to a triangle of equal area, and having its base in AB produced.

*(144) Two circles, A and B, each having a diameter of 1″, have their centres 1·66″ apart. Draw a straight line between these circles that shall be tangential to both.

(145) Construct a square and equilateral triangle, each having an area of 3·8 square inches.

*(146) Draw two circles with radii of 1·25″ and 1·75″ respectively, to touch each other externally, and an arc with a radius of 3·5″ touching externally the two circles.

*(147) Construct an equilateral triangle, having an area of $3\frac{3}{4}$ square inches, and place in it a square having one of its sides resting on one side of the triangle.

(148) Find a point C, 1″ from B, and 2·5″ from A, the extremities of a straight line 2·45″ long. Point C is the centre of a circle of ·75″ radius. Draw a second circle of 1″ radius tangential to the circle and straight line.

(149) Draw any two straight lines at any angle with each other, but not meeting. Draw a circle that shall touch them both.

*(150) Draw an ellipse having axes of 5″ and 3″ respectively. Assuming its centre to be unknown to you, show by what geometrical method you would ascertain it.

*(151) Draw three circles, each touching two others, their radii being 1·39″, ·45″, and ·85″. By means of tangents place them in a scalene triangle, and give the length of its three sides.

*(152) Draw an equilateral triangle equal in area to the sum of two equilateral triangles, one having a perimeter of 3·31″, and the other of 10·17″.

(153) On a base 2″ long describe an isosceles triangle of 4″ side, and divide it into four triangles equal to each other and similar to the original triangle.

*(154) Construct a square of 2·87″ side, and in it inscribe an isosceles triangle, having its base equal to 1·56″, and its apex in one angle of the square. In this triangle, and in each of the three triangles that are external to it, place a circle.

(155) About a pentagon of 1″ side construct a pentagon of 1·9″ side, its sides being parallel to and equidistant from those of the first.

*(156) Find a point P in a line AB (3″ long) produced, so that AP : AB : : 7 : 4.

*(157) Draw a square of 2·5″ side, and divide the square into three equal parts by lines drawn from one corner.

*(158) Construct a regular pentagon whose diagonal shall be 3″. The diagonal is from A to C in the figure ABCDE.

*(159) Divide a square of 3″ side into three equal areas by lines drawn parallel to a diagonal.

(160) Draw an isosceles triangle of 3·5″ area, the vertical angle being 35°.

*(161) The semi-conjugate diameters of an ellipse are 2·5″ and 1·3″ in length, and contain an angle of 60°. Draw the curve and determine the axes.

*(162) Draw a triangle two of whose sides are 2·5″ and 3·25″, the angle opposite the shorter one being 40°. Draw also the circumscribing circle.

(163) In a square of 3″ side inscribe an octagon, so that the alternate sides of the octagon shall coincide with the sides of the square.

(164) The side of a pentagon is 1·5″. Draw an equilateral triangle of the same area as the pentagon.

*(165) A parallelogram whose sides are 4″ and 1·2″, and included angle 50°, is given. Determine a rhombus of equal area, and having the same included angle.

*(166) Three points, P, Q, R, are thus situated: PQ is 2″, QR 2·5″, PR 3·75″. Determine points in the circle which would pass through them, the centre being supposed inaccessible.

*(167) Draw a triangle having its base 2″, the angle opposite the base 42°, and its altitude 1·75″.

(168) Two circles are given, radius 1″ and ·5″ respectively, their centres being 2·5″ apart. Draw a circle of 1·5″ radius to touch both, but to contain the smaller one.

*(169) To a circle of 1·25″ radius draw two tangents which shall contain an angle of 60°.

*(170) The perimeter of a rectangle is 9″. Construct it so that its area shall be 4·25 square inches.

*(171) Construct a square whose area shall be $\frac{1}{3}$ of that described on a line 2·75″ long.

*(172) Divide a line AB, 3·5″ long, in a point P, so that the rectangle contained on AB and AP may be equal to the square upon BP.

*(173) Draw a triangle whose sides shall be as 2 : 3·5 : 4, and whose circumscribing circle has a radius of 1·5″.

*(174) Draw a pentagon whose area shall be 5·5 square inches.

*(175) Divide a line 3·5″ long into two segments, so that the area of the rectangle contained by those segments may be $1\frac{1}{4}$ square inches.

*(176) A point P is 1·75″ distant from the centre of a circle of 2·5″ diameter. Draw through P a straight line cutting the circle in Q and R, so that QR shall be twice PQ.

*(177) Draw the curve described by a point on the surface of a disc, and $\frac{3}{8}$″ from its edge, while the disc rolls along a straight line. Diameter of disc 2·5″.

*(178) A and C are two points, 3·25″ apart. B is a third point, 1·25″ from A, and 2·75″ from C. Given that A and C are the foci of an ellipse, and that B is a point on the curve, draw the curve.

(179) Describe a circle enclosing and touching three other circles of 0·6″, 0·8″ and 1″ radius respectively, each of which touches the other two.

*(180) Construct a triangle having a base of 3·5″, a perimeter of 10″, and an area of 4·5 square inches.

*(181) From a given isosceles triangle, cut off a trapezoid which shall have the same base as the triangle, and its remaining three sides equal to each other.

*(182) Construct a triangle whose perimeter is 7″ and whose sides are as 2 : 4 : 5.

(183) Given the base, altitude, and vertical angle, to construct the triangle.

*(184) A line AB is 3″, and AC is 2″. Find a point D in it such that AB × CD = AD × BC. Also find a point D in AB produced, such that AB + CD = AC + BD.

*(185) Construct an irregular five-sided figure ABCDE under the following conditions:—

Sides.	Diagonals.	Angle.
AB = 2·2″	AC = 2·6″	BCD = 75°
BC = 1·6″	BE = 2·4″	
CD = 2·2″		
DE = 1·5″		

*(186) Describe a series of circles in succession, tangential to two given converging lines,—the diameter of the smallest circle being 1″.

*(187) Determine by construction $\sqrt{3}$ of a line 1″ in length, with the compasses only.

*(188) Divide the area of a circle of 3″ diameter into four parts equal in area and periphery by means of semicircles.

(189) The sides of a triangle are as 2·5 : 3 : 4, and the radius of the inscribed circle is ·75″. Construct it.

*(190) A point P is 1″ from the circumference of a circle of 1″ radius. Draw a line PR cutting the circle in QR, so that QR may be 1·25″ long.

*(191) A line 3″ long moves with its extremities in two lines at right angles. Determine the curve traced out by a point in the line at 1″ from its end.

*(192) A circle of 1″ radius rolls along a straight line; draw half the curve traced by a point in the circumference of the circle.

(193) Describe a circle of 1″ radius. Inscribe five circles in it, and describe ten circles about it.

*(194) Plot an angle of 73° with the protractor. Divide it into four equal parts, and in each part inscribe a circle of one inch diameter.

*(195) ABC is a triangle having the angle at A 60°. AB is 2″, and AC 3″ long. P is a point within the triangle, and AP is 1″. Trisect the triangle by straight lines drawn from P.

(196) About a given triangle ABC describe another, whose sides shall be parallel and equidistant from those of the former, one side DE being given.

*(197) On a line AB, 1·7″ long, as base, construct a regular octagon. On line AB as base, draw within the octagon an equilateral triangle. Draw lines from all the angles of the octagon to the apex, and in each of the eight resulting triangles place a circle.

*(198) On a chord 2·6″ long describe the segment of a circle to contain an angle of 128°. Measure and write down the length of the radius of the circle, and the size of the angle of the sector having the same chord as the segment.

*(199) Draw a circle of 2″ diameter; show a geometrical means of finding the centre; and from B, a point 3″ from the centre, draw a tangent. Letter the point of contact C, and divide BC into three equal parts in D and E. On DE, one of these parts, construct a regular pentagon.

*(200) Draw a regular heptagon of 1½″ side, and within it place seven equal circles, each touching two others and two sides of the polygon.

*(201) Two points are 2″ and 2·5″ from the centre of a circle of 1″ radius, and 3″ from each other. Draw the circle which, passing through these two points, shall touch the given circle.

(202) Draw two tangents to a circle of 1″ radius to meet at an angle of 60°.

*(203) Construct an irregular seven-sided polygon ABCDEFG under the following conditions:—

Sides.	Diagonals.	Angles.	
AB = 1·25″	BP (in BE) = 2·3″	BPD = 113°	EPF = 65°
AE = 3·72″	PD = 2·15″	BPG = 67°	
BE = 3·5″	PG = 2″		
BC = 2″	PF = 1·58″		
DC = 2″			

*(204) A line AB is 4″, and AC is 2¼″. Find a point D in it,

(*a*) Such that $AB \times CD = AD \times BC$.

(*b*) Find a point D in AB produced, such that $AB \cdot CD = AC \cdot BD$.

*(205) Construct a triangle under the following conditions:—

One side AB = 2·25″. The perimeter 8″, and $AB : AC :: BC : AC$.

*(206) A straight line is 2″ from the centre of a circle of 1″ radius. Draw the curve, every point of which is equidistant from the line and from the circumference. The arc to be continued till it meets the diameter parallel to the line.

*(207) A point F is 2″ from a line. Draw half the curve, the distance of every point of which from the given point is to its distance from the line as 2 : 3.

*(208) Show the construction for determining the arc of a circle passing through three given points, when they are so nearly in a straight line that the one usually adopted would fail. For instance, take the three points A, B, C, and make $AB = 2\frac{3}{4}''$, $BC = 1\frac{3}{4}''$, $AC = 4''$.

*(209) Draw the hypocycloid produced when the directing circle is of 1·75″ radius, and the generating circle is of ·58″ radius.

*(210) Draw an ellipse whose axes are 3·5″ and 2·5″, and from any point outside it (not in the prolongation of either axis) draw tangents to it.

*(211) A line $1\frac{1}{2}''$ long represents a square of 2″ side. Determine the length of a line which would represent on the same scale a hexagon of $1\frac{3}{4}''$ side.

(212) Construct a triangle having given the base $2\frac{1}{4}''$, one of the angles at the base 55°, the sum of the remaining two sides $5\frac{1}{4}''$.

*(213) If a line $\frac{1}{2}''$ long represents the area of an equilateral triangle of 2″ side, obtain a length by construction which will represent the area of an octagon of $1\frac{1}{4}''$ side.

(214) Draw any irregular four-sided figure, no side less than $1\frac{1}{4}''$. Construct a similar figure whose sides are $1\frac{1}{2}$ times those of the first figure.

*(215) The sum of the diagonal and one side of a square is 6″. Construct the square.

*(216) Construct a hexagon equal to an octagon of 1″ side.

(217) Describe a circle enclosing and touching three other circles of 0·63″, 0·82″, and 1·1″ radius respectively, each of which touches the other two.

(218) Show the method of finding the major and minor axes of an ellipse, and draw a tangent to it at a point P in the curve.

*(219) Construct a triangle having a base of 4·25″, a perimeter of 12″, and an area of 5·5 square inches.

*(220) The line joining one corner of a square with the centre of the opposite side is 3″ long. Draw the square.

*(221) Two lines A and B converge to a point without the paper. Take any point P and draw a third line through P converging to the same point.

*(222) Draw a four-sided figure ABCD:

$AB = 1{\cdot}2''$ $CD = 2{\cdot}2''$ $BD = 2{\cdot}4''$
$BC = 1{\cdot}5''$ $AD = 2{\cdot}5''$

Draw a rhombus equal in area to the quadrilateral ABCD.

(223) Divide a square of 3″ side into four equal areas by lines drawn parallel to a diagonal.

(224) Draw a circle of 1″ radius, and take a point P 1·5″ from the centre. From P draw a line to cut the circle in Q and R, so that PQ shall be $\frac{1}{3}$ of the whole line PR.

*(225) Construct a triangle having its vertical angle 50°, its base 2″, and the line bisecting the vertical angle dividing the base in the ratio of 2 : 3.

*(226) Draw the curve traced by a given point C in a given straight line AB, which moves with its extremities in two straight lines, DE and DF, placed at right angles.

(227) Draw a line through a given point A situated between two given converging lines BC and DE, making equal angles with the two given lines. Also

(*a*) Draw straight lines from any two given points, A and B, outside a given straight line, CD, meeting CD so as to make equal angles with the given line; (*b*) to meet CD, so that they may be equal in length; and (*c*) to find a point, A, in the base of any given triangle, BCD, from which the two lines drawn parallel to the sides to meet them are equal.

(228) (*a*) Inscribe a regular octagon within a given square, having its alternate sides coinciding with the sides of the square; and (*b*) its alternate angles touching the sides of the given square.

*(229) Inscribe within a given square of $2\frac{1}{2}''$ side another square having its angles in the sides of the first but $\frac{2}{3}$ its area.

(230) Draw a semi-elliptical arch within a rectangle whose sides are AB, 3″, and CD, $2\frac{1}{2}''$, AB being a conjugate axis.

(231) Within a square of $2\frac{1}{2}''$ side inscribe a rectangle, the length of two sides being each $2''$ in length. The corners of the rectangle to be in the sides of the square.

*(232) The angle between two sides of a rhombus is 60°, the length of the sides $3''$. Draw an ellipse that shall touch the four sides of the rhombus.

*(233) About a rectangle $3''$ by $1\frac{1}{2}''$ draw an ellipse passing through the corners of the parallelogram.

*(234) Divide a circle into three equal areas by concentric annuli.

*(235) Divide a circle into three parts equal in area and periphery by means of semicircles.

*(236) Draw a triangle having sides of 200 feet, 250 feet and 300 feet, scale $1'' = 100$ feet. Divide this triangle into three equal areas by lines drawn from the apex.

*(237) The sides of three different squares measure $1''$, $1\frac{1}{4}''$, and $1\frac{1}{2}''$. Draw a square equal in area to the sum of the three squares.

*(238) Draw a square equal in area to the difference between two given squares of $2''$ and $1\frac{1}{2}''$ side.

*(239) Describe a quatrefoil of semicircles within a square, each semicircle touching two sides of the square.

*(240) Within a circle of $3''$ diameter inscribe five equal semicircles having their diameters adjacent.

(241) About a circle of $2\frac{1}{2}''$ diameter describe a regular heptagon.

*(242) Draw a regular hexagon of $1''$ side, and within it place another hexagon having the same centre and each side $\frac{3}{4}''$.

*(243) Draw a regular pentagon of $1''$ side, and about it place another pentagon having the same centre and each side $1\frac{1}{4}''$.

(244) Within a regular heptagon inscribe the largest possible equilateral triangle.

(245) The perimeter of a pentagon is $7\frac{1}{2}''$. Draw the pentagon.

*(246) Construct a regular decagon of $1\frac{1}{4}''$ side, and divide the decagon into equal isosceles triangles. Within each isosceles triangle inscribe a square.

*(247) Within an equilateral triangle inscribe three equal semicircles, each semicircle touching two sides of the triangle.

(248) Divide an equilateral triangle into four equal equilateral triangles, and inscribe a circle within each triangle.

*(249) Draw a triangle whose sides are AB $2\frac{1}{2}''$, BC $2''$, and AC $1\frac{1}{2}''$. Consider points A and B as the foci of an ellipse, and a point C in the curve given. Draw the ellipse.

(250) Draw an equilateral triangle having its perimeter $6''$, and divide it into four equal equilateral triangles.

(251) The sides of a triangle are 200, 250 and 300 yards long. Divide the triangle into two equal areas by a line drawn from one corner. Scale 100 yards $= 1''$.

(252) The sides of a triangle are 2 feet, $2\frac{1}{2}$ feet, and 3 feet long. Place another triangle within it having a base $1\frac{1}{2}$ feet, both triangles having a common centre. Scale $1''$ to 1 foot.

*(253) The perimeter of a trapezium is $8''$, and its sides are as 2, 3, 4 and 5. Draw the trapezium.

*(254) Within an oblong place a second oblong having the same centre and its long sides $\frac{3}{5}$ the length of the long sides of the given one.

(255) Two circles of radii $1''$ and $\frac{1}{2}''$ have their centres $2''$ apart. Describe a circle of $\frac{3}{4}''$ radius which shall touch both.

(256) Draw three circles having diameters $1''$, $2''$ and $2\frac{1}{2}''$ touching each other.

*(257) Draw a sector of $2''$ radius and having an angle of 100°. Within the sector inscribe a circle.

*(258) A trapezium has two sides, each $1\frac{1}{2}''$ long, and the enclosed angle is 80°. The other two sides are each $2\frac{1}{2}''$ long. In this trapezium inscribe a circle.

(259) Draw a square $\frac{1}{5}$ the area of a given square.

(260) Draw a triangle $\frac{1}{3}$ the area of a given triangle.

(261) Draw an oblong the area of a given oblong.

*(262) The diameters of two circles are 3″ and 2″. Draw a circle equal to the difference in area between the circles having the given diameters.

*(263) Find lines equal to $\sqrt{3}$ and $\sqrt{5}$, the unit being 1″.

*(264) Construct a triangle having one side 3″ long, angles adjacent to that side being 30° and 45°, and within it inscribe a square and about it describe a circle. In this circle inscribe a pentagon, one of its angles touching the circumference at the same point as one of the extremities of the longest side of the triangle.

*(265) Describe a circle of 1″ radius. Divide the circumference into sixteen equal parts, and draw radii from the points of division, stopping them at a circle of ·2″ radius having the same centre.

*(266) Draw a circle having a diameter of $4\frac{1}{3}$″. In this inscribe an octagon, and in the octagon a square. State the length of one side of each of these.

*(267) Within a hexagon of $2\frac{3}{10}$″ side draw a hexafoil of semicircles to which the sides of the hexagon shall be tangents. On the diameter of each semicircle as a diagonal construct a square.

*(268) In a circle 3″ diameter place a quatrefoil of semicircles of which the diameters shall be adjacent, and from the centre of each semicircle and of the circle draw circles of ·35″ radius.

*(269) Draw a third proportional AC to AB and AD, $1\frac{1}{8}$″ and $1\frac{1}{2}$″ long respectively. Secondly, divide a line EF, 2″ long, into extreme and mean ratio.

*(270) At point A in a line AB draw three lines making angles of 33°, 79°, and 113° respectively with AB. In each angle inscribe a circle of $1\frac{1}{2}$″ diameter.

*(271) Draw two lines, AB and AC, each 4″ long and making an angle of 32° at A. Find a point D on either of the lines $2\frac{1}{4}$″ from A. Draw a circle tangential to the given lines and touching one of them in D, and from the same centre two other circles of ·6″ and ·27″ radius respectively.

*(272) Draw three equal circles in contact with each other and inscribed in a circle of 1·5″ radius. Circumscribe the outer circle by an equilateral triangle, the sides touching the circle in the points of contact with it of the inscribed circles. Circumscribe this triangle again by a regular hexagon, its alternate angles coinciding with those of the triangle. In each of the three resulting isosceles triangles lying outside the equilateral triangle place a square having one of its sides resting on the longer side.

*(273) Draw a rhombus having a side of 2″ and an angle of 60° given. In this place a square having its angles resting on the sides of the rhombus. On each side of this square draw another as large as the bounding lines of the rhombus will permit.

*(274) Draw a straight line AB, 4·8″ long, and from its extremities A and B, without producing it, erect perpendiculars AD and BC, each equal 3·2″. Join CD, and divide the parallelogram so formed into six equal squares. In each square inscribe a circle.

*(275) Upon a base BC, 2″ long, describe a triangle ABC, having the side AC 1·75″, and the angle ABC 55°. Upon AB construct a square ABEF, and on AC a square ACGH. Join FH, and reduce the whole figure FEBCGH to a triangle of equal area.

*(276) Draw six equal circles each touching those adjacent to it, and so placed that the centres will all be found on the bounding lines of an equilateral triangle of $2\frac{1}{2}''$ side.

*(277) Construct a square having an area of 1″, and a second square in the proportion as 3 is to 1 of the first. Place the small square within the large one, so that its sides are parallel to and equidistant from it.

*(278) On a chord 2·4″ long describe the segment of a circle to contain an angle of 54°. With a radius of 1·15″ inscribe a circle to touch the chord and the arc of the segment.

*(279) In a hexagon having a perimeter of $7\frac{1}{2}''$ place a square, each of its angles resting on a side of the hexagon. Divide this square into four smaller ones, and in each place an equilateral triangle, the four apices to meet in one point.

*(280) Draw a straight line AB, 4″ long, and from its extremities erect perpendiculars AC and BD, 2·5″ and 1·8″ long respectively. Find a point in AB equidistant from C and D.

*(281) Describe a circle—(1) to touch a given circle and a given straight line at a given point D. (2) Describe a circle passing through two given points AB, and tangential to a given straight line CD. (3) Describe a circle tangential to two intersecting lines and passing through a given point X lying between them.

*(282) Draw two concentric circles, having radii of 1″ and 2″. In the space between these place seven circles at equal distances consecutively from each other, having a radius of $\frac{5}{12}$″, and their centre half-way between the two larger circles.

*(283) With a centre C, and radius of 2″, describe a sector of a circle having the angle at C 60°. In the sector inscribe a square having one of its corners in the arc AB.

*(284) Construct an isosceles triangle having a base of 2″ and a vertical angle of 37°. Obtain a similar triangle of half the area.

*(285) Draw five concentric squares 0·15″ apart, the smallest having a side of ·9″. Ink in the squares with lines that increase in strength from the smallest to the largest.

*(286) Describe a circle having a radius of 2·12″. By means of four concentric circles divide its area into five equal parts. From any point in the outer circle draw a tangent to the innermost.

*(287) Draw a rectangle having sides 2·48″ and 5·12″ long. Trisect each angle, and produce the lines until they touch the bounding lines of the figure. Letter all points, and give the lengths of the trisecting lines.

*(288) Construct a regular pentagon and an equilateral triangle, each of 4 square inches area.

*(289) Within a circle of $1\frac{1}{2}$″ radius place a trefoil of tangential arcs of equal circles, and from the centres of these draw three circles having diameters of 1·1″, ·74″, and ·55″, increasing each smaller circle in thickness of line when inked in.

*(290) Upon two bases of 2″ and $2\frac{1}{2}''$ respectively construct isosceles triangles having angles at their bases of 50° and 75° respectively. Construct a square having an area equal to their united surfaces.

*(291) Draw a circle of 1″ radius and divide its circumference into 6 equal arcs. Describe an arc of a circle of 1″ radius from each point of division, stopping these arcs at the circumference of the first, and each passing through the centre.

*(292) Two points are each $3\frac{3}{4}''$ from the centre of a circle of $1\frac{1}{4}''$ radius and $2\frac{3}{4}''$ from each other. Describe a circle that shall pass through the two points and touch the given circle.

*(293) Describe a square of 4″ side, and obtain two other squares together equal in area to the first, and having a ratio of 1 to 2.

*(294) Determine the side of a square of 7″ area. Draw the square, and trisect it by lines drawn from one of its angles.

*(295) Given 1″ as the unit, obtain by geometrical construction $\sqrt{\frac{5}{2}}$.

*(296) Construct a square of 5″ area, and in it inscribe a second square having its four corners in the four sides of the first, but its area $\frac{1}{3}$ less.

*(297) Draw a straight line AB, 6″ long, bisect it in C, and erect a perpendicular CD 1″. Draw the arc of a circle that shall pass through the points A, B and D without using the centre of the circle.

*(298) Draw two straight lines inclined to each other at an angle of 35°, and describe a circle of $\frac{1}{2}''$ radius to touch both of them. Draw a second circle touching the first and the two straight lines.

*(299) Draw the curve of an ellipse by any method you please, providing the major axis is $\sqrt{9''}$ and the minor axis $\sqrt{5''}$.

*(300) Given a scalene triangle, describe three circles with their centres at the angles, each touching the other two.

CONCERNING SCALES.

It is necessary, in the study of military surveying, engineering, architecture, &c., that the student should understand the construction and use of Scales. The construction of Scales requires judgment and ingenuity, and the application of them a certain amount of neatness and precision.

A Scale is a line of standard length divided into a definite number of equal parts, and represents in convenient dimensions, without distortion, either large or small measurements.

A drawing is said to be made to scale when its parts bear a certain fixed proportion to the parts of the object it represents.

Let A————————B be a line that actually represents 100 yards. AB will be found to measure 1″—*i.e.*, a length of 100 yards is represented by a line 1″ in length; therefore the line is said to be drawn to a scale of 100 yards to 1″. We must now find the proportion of the drawing to the original object—bring 100 yards to inches. The number of inches in 100 yards = 100 × 36 = 3600 inches. It is therefore evident that every line to the original object is 3600 times the line which represents it in the drawing; or every line in the drawing is $\frac{1}{3600}$th part of the corresponding line of the object—*i.e.*, the representative fraction of the scale is $\frac{1}{3600}$.

The student must clearly understand what is meant by the Representative Fraction, to find which he must reduce the number of units represented by 1″ to inches.

The representative fractions are used to express the ratio of any line in a drawing made to scale, to the corresponding given line of the original; thus, if the fraction of a scale is $\frac{1}{20}$th, it shows that the drawing is $\frac{1}{20}$th of the real size of the object it represents, or 1″ represents 20″.

Therefore:

If	1	inch	represents	1 foot,	the fraction	of the scale	is	$\frac{1}{12}$
,,	1	,,	,,	4 feet,	,,	,,	,,	$\frac{1}{48}$
,,	1	,,	,,	8 ,,	,,	,,	,,	$\frac{1}{96}$
,,	$1\frac{1}{2}$	,,	,,	1 yard,	,,	,,	,,	$\frac{1}{24}$
,,	1	,,	,,	1 pole,	,,			$\frac{1}{36 \times 5\frac{1}{2}} = \frac{1}{198}$
,,	1	,,	,,	1 furlong,	,,			$\frac{1}{36 \times 5\frac{1}{2} \times 40} = \frac{1}{7920}$
,,	1	,,	,,	50 yards,	,,			$\frac{1}{50 \times 36} = \frac{1}{1800}$
,,	1	,,	,,	1 mile,	,,			$\frac{1}{1760 \times 36} = \frac{1}{63360}$
,,	5	,,	,,	150 yards,	,,			$\frac{5}{150 \times 36} = \frac{1}{1080}$

The representative fraction is, therefore,

$$\frac{\textbf{Any line in the drawing in inches.}}{\textbf{What that line represents in inches.}}$$

PLAIN SCALES.

A Plain Scale is the simplest form of a scale of equal parts, set off on a straight line, as feet and inches, or inches and tenths.

A PLAIN SCALE OF FEET AND INCHES.

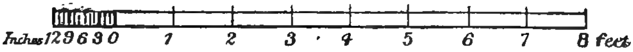


FIG. 1.

(1) To construct a plain scale of feet and inches long enough to measure 12 feet from, when 1″ represents 3 feet.

$$\therefore\ 1 \times \tfrac{12}{3} = 4'', \text{ length of scale.}$$

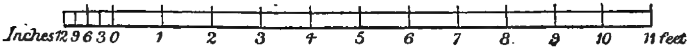


FIG. 2.

($\tfrac{3}{4}$ths Scale.)

The fraction of the scale is $\dfrac{1}{3 \times 12} = \dfrac{1}{36}$.

Draw a line 4″ in length and divide it into twelve equal parts—each part represents 1 foot; subdivide the first primary division to represent inches.

Note.—The bottom line of a scale is shown thicker than the top line; primary divisions are figured from left to right, subdivisions from right to left.

Heavy lines in a scale are merely for contrast.

(2) Draw a plain scale of feet to measure 25 feet from, when 3 yards is represented by 2″. What is the fraction of the scale?

$$\therefore\ 2 \times \tfrac{25}{9} = \tfrac{50}{9} = 5{\cdot}\dot{5} \text{ or } 5{\cdot}56'' \text{ nearly, length of scale.}$$

Draw a line 5·56″ long and divide it into twenty-five equal parts. The method of drawing all plain scales is similar to Fig. 1.

The fraction of the scale $= \dfrac{2}{3 \times 36} = \dfrac{1}{54}$.

Note.—Since in the representative fraction is expressed the number of inches represented by 1″, the scale may be drawn when this fraction is given.

(3) A scale is required to measure 20 feet from, when the representative fraction is $\tfrac{1}{48}$.

$$\therefore\ \frac{1 \times 20 \times 12}{48} = 5'', \text{ length of scale.}$$

For drawing the scale, proceed as in former plain scales.

(4) A scale is required to measure 20 miles from, the representative fraction being $\frac{1}{253440}$.

$$\therefore \frac{1 \times 20 \times 1760 \times 36}{253440} = 5'', \text{ length of scale.}$$

DIAGONAL SCALES.

It will be seen that the solution of some of the problems on scales requires a decimal notation. A specimen of a diagonal scale is given, from which the student can observe the method of measuring lines and distances with greater accuracy than could be done by means of a simple scale. Let AB be the unit of length to be divided into X parts, this being resolved into two factors, Y, Z. AB is divided into Y parts, the Z lines at any convenient equal distances being drawn parallel to AB; two lines perpendicular to AB are drawn, one through each extremity. The distance between these on the farthest parallel being again divided into Y parts, the points of division are joined by oblique lines, as shown in the figure, and thus each of the Y divisions of AB is in fact subdivided into Z equal parts, or the whole line into X parts. (Let AB represent 100 in this case.)

$$\therefore \ Y \times Z = X \text{ parts—}i.e., \ 10 \times 10 = 100.$$

A DIAGONAL SCALE.

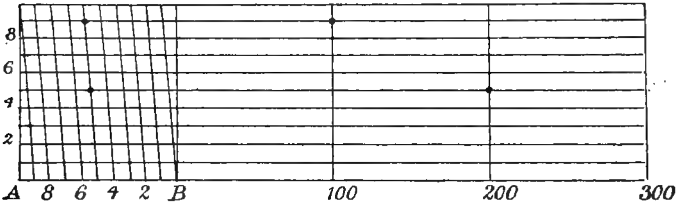


FIG. 3.

The distance between the dots on the 9th parallel shows 159.
„ „ „ „ 5th „ „ 255

A diagonal scale must be carefully made, or it is useless.

On ordinary boxwood scales a decimal scale is generally given on one side, of inches or of half inches. By the application of distances measured from the scale, fig. 3, tenths or hundredths of an inch may be measured. Considerable practice is required to get familiar with a diagonal scale.

(5) Draw a diagonal scale of 5 feet to 1″, to show inches. Assume 25 feet.

$$\therefore \frac{1 \times 25}{5} = 5'', \text{ length of scale.}$$

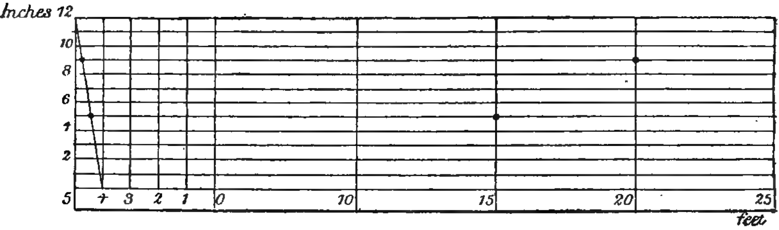


FIG. 4.

(¾ths Scale.)

Note.—Diagonal scales are used for measuring off more minute distances than can be done by an ordinary scale.

Method of drawing the diagonal scale.—Draw a line 5″ long and divide it into five equal parts, and the first primary division into five equal parts. Each subdivision will represent 1 foot. Draw twelve parallel lines the same distance apart as shown; also draw perpendiculars through the points of division. Across the subdivision on the extreme left draw a diagonal—this increases from left to right 1″—on each parallel line.

Between the dots on the 5th parallel we measure 14ft. 5in.
" " 9th " " 19ft. 9in.

It is obvious that any measurement from 1″ to 25 feet may be taken from the scale.
)

All diagonal and decimal scales are drawn on the same principle.

Note carefully the manner the diagonal scale is figured, and below the required parallel lines draw a thick line, and write feet and inches, or whatever the scale represents, on the extreme left and right of scale.

(6) It is required to construct a diagonal scale of 8 miles to an inch, to show furlongs. Assume 45 miles.

$$\therefore \frac{1 \times 45}{8} = 5{\cdot}62'', \text{ length of scale.}$$

$$\text{Representative fraction, } \frac{1}{8 \times 1760 \times 36} = \frac{1}{506880}.$$

Draw a line 5·62″ long and divide it into nine equal parts, and the first primary division into five equal parts. Each part will represent one mile. Draw eight parallel lines the same distance apart (8 furlongs = 1 mile), and draw perpendiculars through the divisions, and draw a diagonal across the subdivision on the extreme left.

(7) Draw a diagonal scale of 1 furlong to 1″, to measure yards.

Make your scale any convenient length, say 5″; each inch represents one furlong. A furlong equals 220 yards, which, resolved to factors, = 11 × 20. So divide the first inch on the scale into twenty parts; each part will represent 11 yards. To measure single yards, draw eleven parallel lines, and proceed as in the other diagonal scales.

$$\text{Representative fraction, } \frac{1}{220 \times 36} = \frac{1}{7920}.$$

(8) The distance between A and B is 5 miles, and is represented on a plan by 1·25″. Construct the scale and show furlongs, when 20 miles is the number assumed.

Draw a line 5″ long and divide it into twenty equal parts.

Subdivide diagonally the first division into eight equal parts, to represent furlongs.

The representative fraction of the scale is

$$\frac{\overset{\overset{1}{\cancel{25}}}{\cancel{125}}}{\cancel{5}\times 1760\times 36\times \underset{4}{\cancel{100}}}=\frac{1}{253440}.$$

(9) The representative fraction of a scale is $\frac{1}{960}$. Draw the scale and show 250 yards.

$$\therefore \frac{1\times 250\times 36}{960}=9{\cdot}37'', \text{ length of scale.}$$

(10) Construct a diagonal scale showing inches, tenths and hundredths.

COMPARATIVE SCALES.

A scale constructed from a given scale to read in some other different measure is called a Comparative Scale.

(11) On a map the distance between two points is 4″, and represents 5 miles. Required a comparative scale of furlongs.

$$5 \text{ miles} : 4'' : : 1 \text{ furlong} : x.$$

Or $\frac{4\times 1}{40}=\frac{1}{10}$ of an inch to represent a furlong.

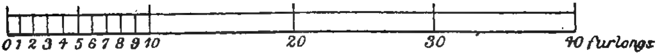


Fig. 5.

(¾ths Scale.)

Therefore draw a line 4″ long and divide it into forty equal parts. Each division will represent 1 furlong, and is comparative or corresponding to the given scale.

(12) I examine a French plan of a building, and find a scale of decimètres, 10 to an inch. I desire to measure English feet. Draw a comparative scale showing 20 feet. (A decimètre = 0·327 feet.)

1″ represents $\cdot 327 \times 10 = 3\cdot 27$ English feet. We have also $3\cdot 27$ feet : 1″ : : 20 feet : $x = 6\cdot 11''$, length of scale.

$$\text{Or } \frac{20}{3\cdot 27} = \frac{2000}{327} = 6\cdot 11''.$$

Draw a line 6·11″ long and divide it into twenty equal parts. Each division will represent 1 foot, and will be comparative to the given scale of decimètres.

(13) A plan is drawn to a scale of 88 feet to an inch. Draw a comparative scale by which any distance from 5 yards to 150 yards may be measured on the plan.

$$\frac{1 \times 150 \times 3}{88} = 5\cdot 11'' \text{ in length.}$$

Draw a line 5·11″ in length and divide it into fifteen equal parts. Each part represents 10 yards. Bisect the first division of 10 yards, so as to obtain 5 yards.

(14) On a scale 60 Russian versts measure 7·5″. Supply a comparative scale of English miles, taking a verst as 1167 yards. Show 50 miles.

$$\frac{50 \times 1760 \times 75}{600 \times 1167} = \text{length of scale, representing}$$

50 English miles.

SCALE OF CHORDS.

A Scale of Chords is one by which, in lieu of a protractor, angles of any proposed number of degrees can be constructed, or angles already laid down measured. This scale is usually found on boxwood and ivory scales, and is indicated by the sign C, or CHO, at its commencement.

(15) To construct a scale of chords.

Construct a quadrant ABC, and divide its arc BC into nine equal parts of 10° each; thus, trisect the arc with the radius of the arc as radius. Divide each angle of 30° into three equal parts by trial. Draw the chord of the arc BC, and from C as centre, to the points of division on the arc as radii, describe arcs cutting the chord BC, and number each point of division in tens of degrees, from 0 to 90, thus transferring

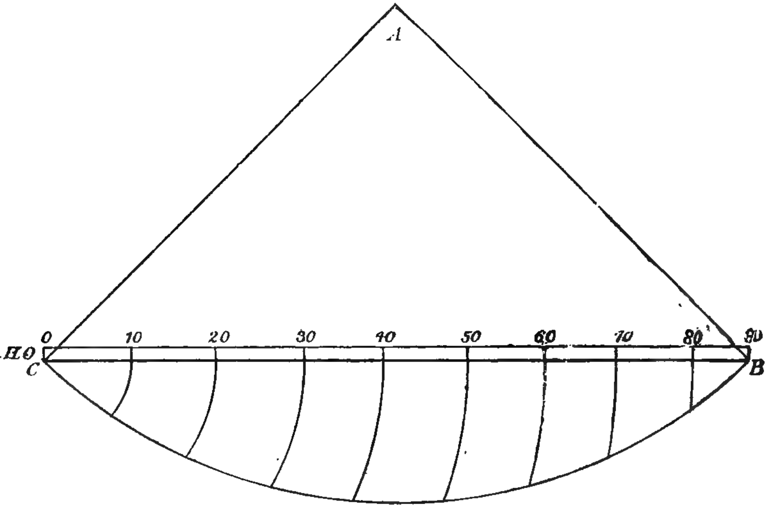


FIG. 6.

the degrees in the arc to the straight line, from either of which the same measurements may be taken.

Method of using the scale of chords.—Whatever angle is required, always take the distance from 0 to 60 as radius, and with centre C describe an arc LM. For an angle of 50°, take the distance from 0 to 50 on the scale of chords, and set it off from L to P. Draw the line CP. The angle PCL is 50°.

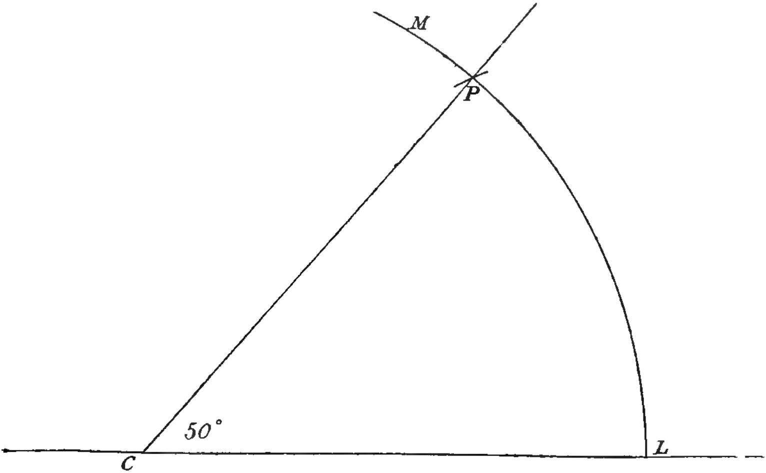


FIG. 7.

THE SECTOR.

A Sector is used to divide lines into segments which shall have to each other a given numerical ratio. (10 Euc. III.) Constructions are greatly facilitated by means of a sector. This is a jointed ruler, on each leg or limb of which are lines radiating from the centre of the hinges; the two marked L (Line of Lines) are those most required. These are divided into equal parts commencing from that centre, each division being again decimally subdivided on the instrument.

It is obvious that by the principle of similar triangles the distances indicated by the dotted lines will be in the ratio of 3 : 6 : 10. For example, the distance 3 and 3 has the same ratio to 6 and 6 as the number 3 is to 6, or one-half. If the dotted line AB measure $2\frac{1}{2}''$, the dotted line 6, 6 will measure $\frac{3}{5}$ of $2\frac{1}{2}''$, or $1\frac{1}{2}''$; the line 3, 3 will measure $\frac{3}{10}$ of AB, or $\frac{3}{4}$ of an inch.

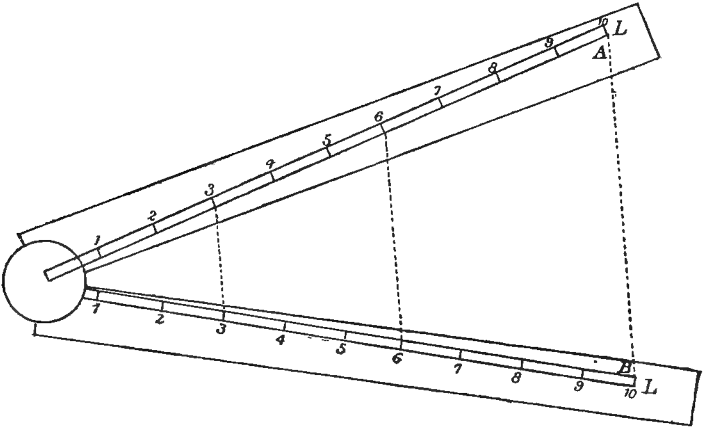


FIG. 8.

(16) To find $\frac{5}{9}$ of a line 3·3″ long.

Take 3·3″ in your compasses and place one point of the compasses in the 9th point of the line L, on one limb of the sector, and open the instrument till the other point of the compasses falls into the corresponding point 9 of the other limb; then the transverse distance between 5 and 5 will be the length required.

(17) To find $\frac{3}{5}$ of a line 4·22″ long.

Take 4·22″ in your compasses and place one point of the compasses in the 5th point of the line L, on one limb of the sector, and open the instrument till the other point of the compasses fall into the corresponding point 5 of the other limb; then the transverse distance between 3 and 3 will be the length required.

Again. On a map a distance of 1·6 represents a space of 80 miles. Complete the scale to 100.

Take the given space 1·6 in the compasses and place it between 80—80. Open the compasses from 100 to 100, which gives the whole length of the scale.

In using the sector care must be taken not to alter the angle at which it is set, while ascertaining the length of a line in a given ratio, and only use the divisions on the lines which pass through the centre of the joint.

MARQUOIS SCALES.

Marquois Scales, called so from the name of the inventor, consist of two rectangular rules 1 foot long, and a right-angled triangle or set square; the set square is so constructed that the hypotenuse is three times the shortest side, and near the centre of the hypotenuse is an index *d*. Besides being able to draw lines parallel to one another, we can also draw them at any required distance apart; this is one property of the Marquois Scales which makes them so valuable to a military student. The principle embodied in the construction of Marquois Scales, each of which consists of two parts, an outer or artificial scale, and an inner or natural scale. The drawing is made to the natural scale, and the numbers written below it signify the number of units, whether of yards, chains, &c., represented by 1″.

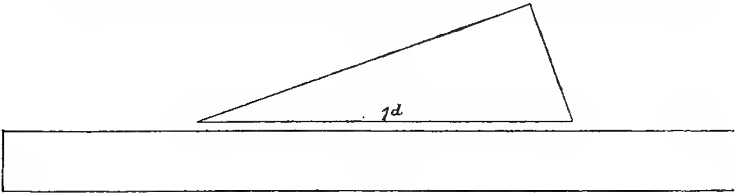


FIG. 9.

Take, for example, the scale of 30. It will be seen that the primary divisions are marked from left to right, and the first division subdivided into ten parts. Taking these subdivisions as single units of measure, three primary divisions will contain 30, and the scale will be called a scale of 30 units to the inch.

The primary divisions upon the artificial scale are marked from zero both ways, and numbered 10, 20, &c. These divisions are three times those on the natural scale, thus giving the scales the same ratio that the longest side of the triangle has to the shortest side.

It is required to draw a line parallel to a given line at a distance of 17 yards from it. We will use the scale 30, which is 30 yards to 1″.

Let the bevelled edge of the set square coincide with the given line, so that the zero on the artificial scale is against the index *d* of the set square; hold the rule fast with the left hand, and slide the set square either to the right or left, until the index *d* is at 17, and draw the line.

It must be understood that the subdivisions in the first primary division on the natural scale may represent any number of units. It is obvious the scales may be varied to any extent.

The proof of the construction depends on 2 Euc. VI.

Again, lines horizontal, vertical, and diagonal may be drawn by the Marquois Scales. By moving the index we can rule lines which are not only parallel, but equidistant also, or the distance may be specified. If the parallels are required to be $\frac{1}{12}$th of an inch apart, use the 60 scale, and move the index over five graduations at a time. If the parallels are required to be $\frac{1}{20}$th of an inch apart, use the 100 scale, and move the index over five graduations at a time.

VERNIERS.

Verniers are small movable scales attached to the index of astronomical and surveying instruments, barometers, &c., and so constructed that when the index moves, the divisions of the vernier successively coincide with the graduations of the fixed scale of the instrument.

For instance, if it were required to read to $\frac{1}{10}$ of a millimètre a barometer whose scale was divided into millimètres, the vernier attached to the index would have 10 divisions equal to 9 divisions of the scale. Hence it follows that if (say) the 4th mark above the index point coincides with a division of the scale, the index will be $\frac{4}{10}$ of a millimètre above the scale division next below it. In some cases it is more convenient to make 10 divisions of the vernier equal to 11 of the scale. With a scale divided to $\frac{1}{4}$ of an inch, by dividing a vernier of 6 or $6\frac{1}{2}''$ into 25 equal parts the position of the index may be determined to $\frac{1}{100}$ of an inch. Again, with a circular scale of half degrees, by dividing a vernier of 29 or 31 half degrees into 30 equal parts the index reads to minutes on the arc. They are seldom used in drawing, but they may in some cases be used instead of diagonal scales.

A Vernier Scale is constructed to measure distances according as the primary divisions represent hundreds, tens, or units; therefore, between the same points on the scale we may measure 116, 11·6, or 1·16.

The method of drawing the scale is to set off on a line of any convenient length a number of inches, which is called the natural scale, AB. The Vernier Scale is XY, drawn under the natural scale.

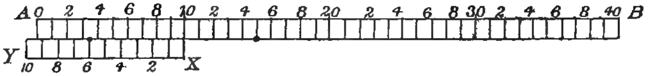


FIG. 10.

($\frac{3}{4}$ths Scale.)

Take a line AB, of any convenient number of inches in length, and divide each inch into ten equal parts. At the primary divisions mark 0, 10, 20, 30, 40, &c., and the subdivisions 2, 4, 6, 8, &c. Take eleven subdivisions from AB, the natural scale, and set off from X to Y and divide into ten equal parts. The scale XY is the Vernier Scale. It is obvious that these subdivisions on the Vernier Scale exceed those on the natural scale $\frac{1}{10}$ of a subdivision, or $\frac{1}{100}$ of a primary division. Taking each subdivision on the natural scale as 10 units, then from X to the division 6 will be 66 units, equals $60+6$—that is, 60 units $+\frac{6}{10}$ of ten units.

The distance between the dots represents 116, 11·6, or 1·16, according as the primary divisions represent hundreds, tens, or units. Let it be required to measure off 116. Place the leg of the compasses on the division 6 of the Vernier Scale, and the other leg on the division 5 on the right of the division 10. From X to 6 on the Vernier Scale is 6 × 11 = 66; and from X to the division 5 = 50, which, added to 66, gives 116.

EXAMPLES.

Questions marked (*) have been set at examinations.

(1) Construct a scale to show 20 feet, when 1″ represents 4 feet.

(2) Construct a scale to show 70 yards, when 1″ represents 9 yards.

*(3) The distance between two places is 4 miles, and is represented in a plan by 1·5″. Construct the scale and show furlongs, when 20 miles is the number assumed.

*(4) Construct a scale of 10 miles to 1″, to measure distances of 1000 yards.

*(5) Draw a scale of 1 mile to 1″, to show furlongs.

(6) Construct a scale of 1 foot to 1″, to measure inches. Show 7 feet.

*(7) Draw a scale of 1 league to 1″, to measure miles. Show 8 leagues, and give the representative fraction.

*(8) The distance between L and C is 30 miles, and measures on a map 18·3″. Draw a scale to the map showing miles and furlongs. State the representative fraction.

*(9) The lines of a drawing are $\frac{1}{90}$ of the real lines which they represent. Provide a scale of feet for the drawing, showing at the least 50 feet.

*(10) On a map a furlong is represented by 1·25″. Draw a scale of poles for this map, and show a line on your paper 227 poles long. ($5\frac{1}{2}$ yards = 1 pole.)

*(11) Make a plain scale to a drawing when 40 feet are represented by 1″. It must be so marked off as to be practically useful, and show 10 feet as the smallest division.

(12) Construct a scale of $\frac{1}{36}$ to show feet and inches by diagonal divisions.

*(13) Draw a plain scale of 12·5 yards to 1″. It must be long enough to measure 70 yards.

(14) Draw a scale of 12 yards to 1″, showing feet by the method of diagonals.

*(15) Draw a decimal scale of $\frac{3}{4}$″ to 1 foot, and show a line equal in length to 5·82 feet.

*(16) A map is constructed so that 1″ represents 45·5 yards. Draw a scale for it from which paces can be measured, the pace being 32″. Assume 250 paces.

*(17) The measurement on a map between A and B is 5″, representing 8·25 miles. Draw a scale for the map, and show a line on the scale equal to 10 miles 5 furlongs.

*(18) Construct a scale to read feet and inches, $8\frac{1}{2}$ feet being equivalent to 5·27″. Give the representative fraction.

*(19) Draw a plain scale of yards of $\frac{1}{2700}$, 500 yards being the greatest and 10 yards the least dimension shown.

(20) Draw a diagonal scale of mètres, comparative to No. 19, and show single mètres. (A mètre = 1·0936 yards.)

*(21) An Englishman wishing to examine a Spanish plan, finds only a scale of Spanish palms, 20 to an inch. Supply him with a corresponding scale of English feet, taking the palm as ·684 English foot. Show 60 feet.

*(22) On a scale 60 Russian versts measure 7·5″. Supply a comparative scale of English miles, taking a verst as 1167 yards. Show 50 miles.

*(23) Draw a scale of $\frac{1}{100}$ to measure Belgian feet. (One Belgian foot = ·90466 English foot.)

*(24) Draw scales of $\frac{3}{978000}$ to show English miles and Russian versts. (A verst = 1166·68 yards.)

(25) Draw a diagonal scale of $\frac{1}{198}$, showing poles, yards and feet. Assume 5 poles.

*(26) On a certain drawing 1250 yards of real magnitude are represented by 15·5″. Furnish a scale for the drawing, and also a comparative scale of French mètres. (One mètre = 1·0936 yards.) Show 500 yards.

(27) Draw a scale of miles $\frac{1}{630000}$, showing furlongs by the diagonal method.

*(28) A map is constructed so that 1″ represents 60 yards. Draw a scale for it from which paces can be measured, the pace being 32″.

*(29) Draw a scale of miles $\frac{1}{63360}$, showing furlongs by the diagonal method.

*(30) Draw a scale of miles, furlongs, and yards, whose representative fraction is $\frac{1}{61336}$, showing 20 yards as the smallest reading.

*(31) Draw a plain scale of 665 paces to the inch, 100 paces being the least, and 5000 paces the largest dimensions shown. Give the calculation and mark the representative fraction, assuming a pace to measure 32″.

*(32) A distance of 37¼ miles is represented on a map by 4·15″. Draw a scale for the map by which single miles may be measured, showing 50 miles. Convert the scale so drawn into a diagonal scale to read furlongs. Give the representative fraction.

(33) Construct a scale of 15 miles to 1″ to measure distances of 1000 yards.

(34) Draw a diagonal scale of 9 feet to 1″ to show inches. Assume 50 feet.

(35) Construct a diagonal scale showing inches, tenths and hundredths.

*(36) A length of 100 yards is found to measure 3·6″ on a drawing. What is the fraction of the scale? Construct a scale to read yards, making it not less than 4″ long.

*(37) Construct a diagonal scale to read mètres with a representative fraction of $\frac{1}{2500}$. (A mètre is 3·28 feet.)

(38) On a plan 5 square inches represent 720 square yards. Draw a scale for the plan.

*(39) Draw a scale of chains $\frac{1}{7000}$, showing poles diagonally. (1 chain = 66 feet = 4 poles.)

*(40) A drawing is on a scale of 4 chains to 1″. Make a diagonal scale for it about 6″ long to read yards. (A chain = 22 yards.)

*(41) Give the representative fraction of a scale on which $3\frac{1}{2}''$ represent 2247 feet. Construct a scale of $\frac{1}{26}$, reading feet and inches.

*(42) Construct a scale of $\frac{1}{72}$ to read decimètres, and show 10 mètres. (A decimètre = 0·328 feet.)

*(43) Construct a scale of $\frac{1}{468}$, showing yards. The scale is to be properly figured, and not less than 7″ long.

(44) Construct a scale of $\frac{1}{200}$ to show 50 yards. Construct a comparative scale of mètres. (A decimètre = 0·328 feet.)

*(45) The plan of a building is a square of 3″ side, the diagonal of which represents 100 feet. Make a scale from which feet and inches may be measured.

*(46) A plan is drawn to a scale of 88 feet to an inch. Draw a comparative scale by which any distances from 5 yards to 150 may be measured on the plan. The scale to be properly figured.

(47) Construct a diagonal scale of 45 feet to 1″ by which single feet may be measured, and write down the representative fraction. Show 250 feet.

*(48) On a plan 6·5″ represent an English mile.

- (*a*) Draw a plain scale of yards to suit the plan, showing 1500 yards, and divide it to show distances of 50 yards.
- (*b*) Draw a comparative scale of Spanish yards. (A Spanish yard = ·927 of an English yard.)

Each scale to be properly figured, and all calculations shown.

(49) On a certain drawing 1250 yards of real magnitude are represented by 15·5″. Furnish a scale for the drawing.

*(50) Make a diagonal scale to read miles, furlongs and chains, if 3 miles are shown by $3\frac{1}{4}''$. Assume 7 miles. Take off 3 miles 7 furlongs 6 chains, and state the representative fraction.

*(51) On a scale 10 furlongs are represented by $2\frac{1}{4}''$. Draw the scale, measure 2 miles 2 furlongs by it, and state the representative fraction.

(52) Draw a diagonal scale to measure tenths and hundredths, ·7 being represented by a line $1\frac{1}{4}''$ long.

*(53) If a line 5″ long represents 4 miles 5 furlongs, how long is the line which represents 3 miles 3 furlongs 3 chains? Give the representative fraction.

*(54) Draw a plain scale of miles and furlongs in which $1\frac{1}{2}$ furlongs equal $\frac{1}{8}$ of an inch. Show 8 miles. Give the representative fraction.

*(55) The distance between two places is 35 miles, and measures on a map 4·4″. Draw a diagonal scale to suit the map, showing 50 miles. What is the distance represented by 2·7″?

*(56) Construct a diagonal scale of feet and inches on which 17 feet would be represented by $1\frac{1}{4}''$. Give the representative fraction, and show 50 feet.

*(57) Draw a line 4·77″ long. Let this represent a length of 3 feet 7″. Produce it to a length of 5 feet 8″.

(58) If 2 miles 3 furlongs are represented on a map by a line 4·37″ long, how long would a line be representing 3 miles 5 furlongs?

(59) On a map 1″ represents $\frac{3}{4}$ of a mile. Draw the scale, and show 3 miles 5 furlongs. What is the representative fraction?

*(60) Draw a scale of feet to measure distances from 1 foot to 50 feet, $5\frac{1}{2}$ feet being represented by ·52″. Draw this scale by the diagonal method, showing inches. Mark off on the scale a distance of 42 feet 5″.

(61) A distance of 19 miles is represented by a line 2·37″ long. Show 45 miles.

*(62) Draw a scale of $\frac{1}{79200}$ to show furlongs.

(63) Draw a line 2·14″ long. Let this represent a line 4 feet 4″ long, and from one end mark off a distance of 1 foot 9″.

*(64) A distance of 3″ on a plan represents 1·9 miles. Construct a plain scale of miles and furlongs to suit the map, showing 4 miles.

*(65) The distance between A and B on a map is 41 miles, and measures 1·7″. Construct the scale by the diagonal method, showing single miles. The scale must be long enough to measure 100 miles.

(66) If a map of the world be drawn to scale of 180 miles to the inch, what is the representative fraction? Draw the scale.

(67) Draw a diagonal scale of $\frac{3}{4}$ of a mile to the inch, to measure miles, furlongs, and chains. Draw a line by this scale 2 miles 5 furlongs 3 chains long.

*(68) Draw a diagonal scale of 850 paces to an inch, to measure distances from 10 to 4000 paces. State the representative fraction, assuming the pace to measure 32″.

*(69) Draw a diagonal scale to measure yards, feet, and inches, 2 feet being represented by 1″. Show distances of 2 yards 2 feet 2 inches, and 1 yard 1 foot 1 inch.

(70) In a scale $\frac{3}{4}$″ represents 5 furlongs. Draw the scale, and measure 2 miles 5 furlongs from it.

(71) Draw a scale of miles, furlongs, and chains, $2\frac{1}{4}$ miles being represented by $3\frac{3}{4}$″.

(72) Draw a diagonal scale of 120 feet to 1″, to measure single feet. Show 400 feet.

*(73) Draw a scale of feet to measure 400 feet, least dimension being 10 feet; 60 feet being represented by ·75″. Give the representative fraction.

(74) A line 1·75″ long represents 5 furlongs. Draw a scale of miles, furlongs, and chains.

*(75) Construct a scale in which 5 furlongs are equal to ·9″. Show miles and furlongs and chains diagonally.

*(76) A distance of 729 yards is represented on a plan by 10·8″. Construct a diagonal scale of yards for the plan, showing 500 yards, by which single yards may be measured. Show all your calculations, figure your scale properly, and write above it the representative fraction. Show the points you would take in order to measure off a distance of 127 yards.

*(77) The measurements of an irregular six-sided field, A, B, C, D, E, F, are taken and found to be as follow:—

Side AB = 250 yards.
„ BC = 190 „
„ CD = 140 „
„ DE = 220 „
„ EF = 150 „

Diagonal EC = 260 yards.
„ BF = 300 „
„ CF = 360 „
Angle ABC = 110°.

Draw a scale of yards having a representative fraction of $\frac{1}{2880}$, and draw a plan of the field to that scale. Write down the length in yards of the side AF and the diagonal AC, and calculate the area in yards of the whole field.

*(78) A map is drawn to a scale of 12″ to a mile. Draw a comparative scale of chains for the map, showing 50 chains. Show all your calculations, figure your scale properly, and write above it the representative fraction. (One chain = 66 feet.)

*(79) Draw a diagonal scale of $\frac{1}{1059}$ to measure single feet. Show 500 feet. Figure your scale properly, and show your calculations. Show by two small marks on the scale the points you would take in order to measure off a distance of 373 feet.

*(80) A map is drawn to a scale of 6″ to an English mile. Draw a plain scale of Spanish yards for the map, showing 2000 Spanish yards, and divided to show distances of 50 Spanish yards. Show all your calculations, figure your scale properly, and write down the representative fraction. (One Spanish yard = ·9277 English yard.)

*(81) Draw a scale of $\frac{1}{320}$ to measure feet. Show 200 feet, and divide the scale to show distances of 5 feet.

*(82) A distance of 1·35 miles is represented on a map by 2·15″. Construct a diagonal scale of chains for the map by which single chains may be measured. Show 250 chains. Show all your calculations, figure your scale properly, and write above it the representative fraction. Draw a line, and from this scale measure a distance of 137 chains. (One mile = 80 chains.)

*(83) The distance between two towns is 27½ miles, and measures on a map 3·25″. Construct a diagonal scale of miles

and furlongs for the map, showing 50 miles. Show all your calculations, figure your scale properly, and write above it the representative fraction. By means of the scale draw a line 23 miles 5 furlongs long.

*(84) On a plan 1250 yards are represented by 15·5″. Draw a comparative scale of French mètres for the plan, showing 500 mètres, and divided to show distances of 10 mètres. (One mètre = 1·0936 yard.)

*(85) Draw a scale of feet, having a representative fraction of $\frac{1}{2040}$, by which distances of 25 feet up to 1000 feet may be measured. Show all your calculations, and figure the scale properly.

*(86) On a Russian map 10½ versts are represented by 1·25 English inches. Draw a scale of English miles for the map, showing 40 miles. (One verst = ·661 of an English mile.)

*(87) It is required to ascertain the distance in mètres and decimètres from a point A, of three points, C, D, and E, all on the same side of a straight line AB, 24½ mètres long. The angles are measured and found to be as follow: BAC = 100°, BAD = 80°, BAE = 55°, ABC = 47°, ABD = 65°, ABE = 85°. Construct a scale of 7 mètres to an English inch, show decimètres by the diagonal method, and by means of your scale draw a plan showing the position of the points C, D, and E. Scale and write down their distances in mètres and decimètres from the point A. A protractor may be used. (One mètre = 10 decimètres.)

*(88) A line AB, 3″ long, represents on a plan a distance of 5 furlongs 15 poles on the ground. Construct a diagonal scale of furlongs and poles for the plan, showing 1 mile. Figure your scale properly, and write above it the representative fraction. Show your calculations. (One mile = 8 furlongs = 320 poles.)

*(89) On a plan a square inch represents 4 acres. Draw a scale of chains for the plan, showing 30 chains. (One acre = 4840 square yards; one chain = 66 lineal feet.)

*(90) The distance between two places is 13 miles, and measures on a map 2¼″. Draw a scale of leagues and miles to

suit the map, showing 10 leagues. Also draw a comparative scale of yards by which distances of 1000 yards may be measured.

*(91) The length of an ordinary pace is 32″; in "stepping short" it is 21″. Draw a scale of $\frac{1}{3000}$ to show 600 ordinary paces, and also a comparative scale of short paces.

*(92) Construct a diagonal scale of chains and links for a plan on which 27 chains are represented by 31″. Show 5 chains.

*(93) Draw a plain scale of feet and inches to measure 7 feet, $1\frac{1}{2}$ feet being represented by 1·3″. Draw also a diagonal scale comparative to the above, to show mètres, tenths of mètres, and hundredths of mètres.

*(94) Construct a scale on which 80 feet are represented by 6″. Show 50 feet.

*(95) Draw a diagonal scale of 120 feet to 1″, to measure single feet. Show 700 feet.

*(96) Find the representative fraction of a scale in which 210 yards are represented by 1·75″. Construct a scale of 13 yards to 1″, and construct a diagonal scale of $\frac{1}{570240}$ reading furlongs.

*(97) The representative fraction of a scale is $\frac{1}{10560}$. Construct a scale of chains to show 1 mile. The smallest unit 1 chain.

*(98) Draw a scale of 2 chains to 1″ to measure 264 yards.

*(99) On a map $67\frac{1}{2}$ miles are represented by 9·3″. Draw a scale of miles for the map, showing 30 miles. Show furlongs by the diagonal method. Show all your calculations, figure your scale properly, and write above it the representative fraction. Show the points you would take in order to measure off a distance of 17 miles 3 furlongs.

*(100) A distance of 37 English miles is represented on a map by 4·3″. Draw a scale of Irish miles for the map, showing 40 Irish miles. (An Irish mile = 2200 yards.)

(101) On a plan 6·5″ represent an English mile, or 1760 yards.

(*a*.) Draw a plain scale of yards to suit the plan, showing 1500 yards, and divide it to show distances of 50 yards.

(*b*.) Draw a comparative scale of Spanish yards. (A Spanish yard = ·927 of an English yard.)

Each scale to be properly figured, and all calculations shown.

(102) A ship sails so that the sum of its distances from two lighthouses is always 4750 yards. The lighthouses are 4000 yards apart. Trace the ship's course for not less than 3000 yards, starting from a point 1200 yards from one of the lighthouses. Scale $\frac{1}{36000}$.

(103) The distance between two places is known to be 13 miles, and measures on a map $2\frac{1}{4}$″. Draw a scale of leagues and miles to suit the map, showing ten leagues.

Draw a comparative scale of yards by which distances of 1000 yards may be measured.

(104) Draw a diagonal scale to read leagues, miles, furlongs. Represent one league by 1″. Show 6 leagues. What is the representative fraction?

(105) On a plan a rectangle 2″ × $2\frac{1}{2}$″ represents 720 square yards. Draw a scale for the plan.

(106) Draw scales of $\frac{3}{500}$ to represent English feet, French mètres, and Greek cubits, if 1 mètre = 3·27 feet, and 1 cubit = ·45 mètres.

(107) Make a scale of chains, 1 mile being shown, and the smallest unit being 1 chain. The representative fraction to be $\frac{1}{10560}$.

(108) Draw a scale of paces to measure distances between 1100 and 20 paces, scale $\frac{6}{5}$″ to a furlong. From the scale draw a line 740 paces long. (1 pace = 30″.)

*(109) Draw a plain scale of 665 paces to the inch, 100 paces being the least and 5000 paces the largest dimension shown. Mark the representative fraction, assuming a pace to measure 32″.

*(110) A military sketch is to be drawn to the scale of $2\frac{1}{2}''$ to the mile. Construct a scale of paces—a pace equals 33″—capable of measuring any distance between 4000 and 100 paces.

(111) A ladder 79 feet long is placed against a building 77 feet high so that the top of the ladder just reaches the top of the building. Draw a diagram to a scale of $\frac{1}{132}$, and measure the angles with a protractor. The scale must also be drawn.

*(112) The distance between two towns is 19 English miles, and measures on a map 2·7″. Draw (*a*) a scale by which single miles can be measured. Show 40 miles. (*b*) A comparative scale to show 10 Austrian miles, if one Austrain mile = 3·3312 English miles.

(113) There are $69\frac{1}{9}$ statute miles to a degree. Draw a scale of statute miles on the scale of 6″ to a degree, and give the representative fraction.

(114) Draw a diagonal scale of 120 feet to the inch, to measure single feet. Show 700 feet.

*(115) A given scale is one of Russian versts, and 1 verst = ·6628 English miles. Draw a comparative scale of English miles showing furlongs diagonally. What is the representative fraction?

*(116) Draw AB 37 feet long. From A draw (on the same side of AB) AC, AD, making the angles BAC, BAD, 56° and 115° respectively. Make AD 46 feet long. From B draw a perpendicular to AB, cutting AC in C. Join CD. Write down lengths of BC and CD in feet, and the magnitude of the angles BCD, ADC. Scale 15 feet to the inch. Assume any two points, OP, outside AD, and from each of them draw lines making angles of 63° with AD.

(117) If 60 Russian versts are represented by 7·5″, and a verst = 1167 yards, draw a comparative scale to read miles. Show 40 miles.

*(118) On an Austrian map a distance of $2\frac{1}{2}$ Austrian miles is represented by 1·15″. Draw a scale of English miles for the map. Show 30 English miles. Figure your scale, give representative fraction, and show all necessary calculations. (One Austrian mile = 3·3312 English miles.)

*(119) A line which measures $2\frac{1}{4}''$ on a plan represents $32\frac{1}{2}$ chains on the ground. Draw a scale of yards for the plan, showing 1500 yards; divide it to show distances of 50 yards. Show your calculations, figure the scale, and give representative fraction.

*(120) Two men start from the same point A, to walk by two different routes to B, where the routes cross. One walks due north from A for the distance of 2300 yards and turns off to the right through an angle of 45°. The other walks due east from A for a distance of 3700 yards, and then due north to B. Draw a scale of yards having a representative fraction of $\frac{1}{28800}$. Draw a plan of their walk to that scale, and write down the total distance traversed by each.

*(121) On a map a distance of $3{\cdot}27''$ represents 2 chains 78 links. Draw a diagonal scale by which distances of 5 links may be measured. Show 5 chains. Figure your scale, show calculations, and give representative fraction. By means of the scale draw a line 3 chains 65 links long. (1 chain = 100 links = 66 feet.)

(122) A French plan has a scale of decimètres, 10 to the inch, and a decimètre = ·327 English feet. Make a comparative scale to read feet. Show 20 feet.

*(123) Draw a scale of yards having a representative fraction of $\frac{1}{1512}$, and by means of the scale draw a plan of a five-sided field ABCDE from the following data:—*Sides*—AB = 85 yards; BC = 130 yards; CD = 105 yards; DE = 170 yards; AE = 135 yards. *Diagonals*—BD = 175 yards; AD = 200 yards. Compute the area of the field in square yards.

*(124) On a given map 325 chains are represented by $3\frac{3}{4}''$.

(*a.*) Construct a plain scale of chains showing 400 chains, and divided to show distances of 10 chains.

(*b*) Construct a comparative scale of yards for the same map, showing 3000 yards, and divided to show distances of 200 yards.

*(125) Draw a scale of yards having a representative fraction of $\frac{1}{3960}$. Draw a straight line AB representing 240 yards of this scale, and besect it in C. On the same side of AB con-

struct the angles ACD = 45°, ACE = 75°, and ACF = 120°. Make CD = 250 yards; CE = 165 yards; CF = 285 yards, and join ADEFB. Reduce the figure to a triangle of equal area, having its apex at E, and its base in AB produced.

*(126) Construct a plain scale of nautical miles, showing cables, and least divisions 10 fathoms. Representative fraction $\frac{1}{120000}$. (One nautical mile = 10 cables = 1000 fathoms = 6086 feet.)

*(127) A man walks from a point A, $3\frac{1}{2}$ miles in a straight line due north to B, when he turns to the right through an angle of 45° and walks in the new direction $1\frac{1}{2}$ miles to C, where he again turns to the right through an angle of 75° and walks $2\frac{3}{4}$ miles to D. From D he walks due south for $2\frac{1}{2}$ miles to E. Draw a scale of $\frac{3}{4}$ mile to 1″, and draw a plan to scale. How far is it from E to A? A protractor is not to be used.

*(128) Two lines AB, 3″, and CD, $3\frac{1}{2}$″, are drawn to scale, and represent distances of 1320 yards and $3\frac{1}{4}$ miles respectively. Give the representative fraction of the scale to which each line is drawn. Show your calculations.

*(129) A distance of 31 miles 5 furlongs is represented on a map by 11″. Draw a diagonal scale of miles and furlongs for the map, showing 15 miles. Give the representative fraction. Draw a line 7 miles 5 furlongs in length by scale.

*(130) Construct a scale of chords to read to 5°. (Radius 4″.) By means of the scale plot angles of 37° and 78°.

*(131) Draw a scale of $\frac{1}{150}$ to read mètres. Show 20 mètres. (1 mètre = 10 decimètres; one decimètre = ·327 English feet.)

*(132) Construct a diagonal scale of $\frac{1}{792}$ to show single yards. Length of scale 150 yards. Draw a line 77 yards in length.

*(133) Given representative fraction = $\frac{1}{9\cdot5}$. Construct a diagonal scale to measure 5 feet, and to show $\frac{1}{8}$ths of an inch. Show by two small dots on the scale a distance of 3 feet $4\frac{7}{8}$″.

*(134) A Spanish plan is drawn to a scale of 10 palms to the inch. Draw a scale showing English feet for the plan, and giving a length of 35 feet. Show your calculations, and give the representative fraction of the scale. (1 Spanish palm = ·685 English feet.)

*(135) Two men start from a point A to reach a point B by two different routes, which leaving A unite at B. One of the men walks due north for 750 yards, and then turns off to the right through an angle of 55°; the other man walks due east from A for 600 yards, then due north to B.

First calculate and then draw a scale with a representative fraction of $\frac{1}{10560}$. Draw a plan of the routes taken by the two men, and write down the total distance each traverses.

*(136) Construct a plain scale of mètres, showing altogether $3\frac{1}{2}$ kilomètres. Least divisions 50 mètres. Representative fraction $\frac{1}{14000}$. (1 kilomètre = 1000 mètres = ·62 of a mile; 1 mile = 1760 yards.)

*(137) The distance between two points on a map is 23·45″. The actual distance is 24 miles 750 yards. Construct a diagonal scale for the map, showing miles, furlongs, and chains. Show by two small dots on the scale a distance of 2 miles 3 furlongs 9 chains, and state the representative fraction. (1 chain = 22 yards.)

*(138) An English map is drawn to a scale of 6″ = 1 mile. Construct a scale for use with this map in French measure. One mètre = 39·37″ (nearly). Give the representative fraction, and indicate on the scale a distance of 1470 mètres.

*(139) In a certain country 10 units of area = an acre. Make a scale for use in this country which will read to tenths and hundredths by the diagonal method. The representative fraction is $\frac{1}{528}$. Indicate by two marks on the scale 3·78 units of length.

*(140) Draw a scale whose representative fraction is $\frac{1}{52800}$. Show furlongs, and represent 50 miles on the scale. Draw a line AB under the scale 7 furlongs in length.

*(141) A mile is represented on a map by 8″. Draw a plain scale of chains for the map, showing 50 chains, and give the representative fraction.

*(142) Draw a diagonal scale of yards to read feet and inches, the representative fraction being $\frac{1}{53}$. Show 10 yards.

*(143) A vertical pole, 100 feet high, casts a shadow on the ground, the sun's rays being inclined to the horizontal at an angle of 38°. If the pole is represented by a line 3″ long, construct a scale to measure the shadow, and find its length in feet by means of the scale.

*(144) Construct a scale of yards, to read feet and inches. Representative fraction $\frac{1}{11}$. Show, by marks upon your scale, a length of 1 yard 2 feet 7″.

*(145) Construct a diagonal scale of miles, furlongs, and chains. Take $1\frac{3}{4}''$ to represent 8 furlongs. Give the representative fraction. Make the scale to read 4 miles. Show by two marks upon your scale the points you would take to measure off a length of 2 miles 1 furlong 7 chains.

*(146) The distance between two towns is $27\frac{1}{2}$ miles, and measures on a map 3·25″. Construct a diagonal scale of miles and furlongs for the map, showing 50 miles. Give the calculations and representative fraction. By means of the scale draw a line 23 miles 5 furlongs long.

*(147) On a plan 1250 yards are represented by 15·5″. Draw a comparative scale of French mètres for the plan, showing 500 mètres, and divided to show distances of 10 mètres. (1 mètre = 1·0936 yards.)

*(148) A map is drawn to a scale of 6″ to an English mile. Draw a plain scale of Spanish yards for the map, showing 2000 Spanish yards, and divided to show distances of 50 Spanish yards. Show all your calculations, figure your scale properly, and write above it its representative fraction. (1 Spanish yard = ·9277 English yard.)

*(149) A man starts from a point A and walks 3 miles 1 furlong to the right in the direction of B. He then turns to his right at right angles and walks $\frac{3}{4}$ of a mile. He then turns 60° to his left and walks 3 miles 5 furlongs. He then turns back 130° to his right and walks $4\frac{1}{2}$ miles. He then turns 70° to his right and walks 2 miles 3 furlongs, arriving at C. Plot

his journey, and measure and write down the distance from C to A. A scale must be drawn $\frac{3}{4}$ of an inch to a mile.

*(150) Construct a diagonal scale showing Russian sagenes and feet. Make the scale to show 100 sagenes. Mark by two dots on the scale a length of 47 sagenes 3 feet. Representative fraction $\frac{1}{1100}$. (A Russian foot is equal to an English foot; 1 sagene = 7 feet.)

GEOMETRICAL PATTERN DRAWING.

THE student should now be able to combine the figures he has learned to draw, so as to form geometrical patterns. To ensure accuracy, care must be taken to make a framework of the lines of construction. It is important always to draw centre lines of construction wherever needed. The student should draw them not only on the same scale as that given, but twice or three times as large, or in any other proportion which may appear suitable. All pattern drawings should be inked in.

(1) First, draw the horizontal and vertical lines of construction in squares; afterwards darken the portions of the lines which form the pattern.

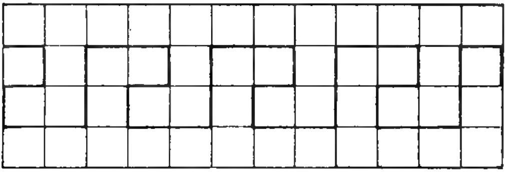


FIG. 1.

(2) Copy this Greek fret to any scale required. Proceed as in Fig. 1.

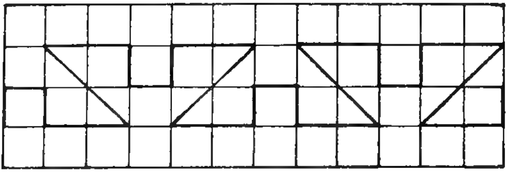


FIG. 2.

(3) Draw the given figure full size, adhering strictly to the figured dimensions. It is based on an equilateral triangle.

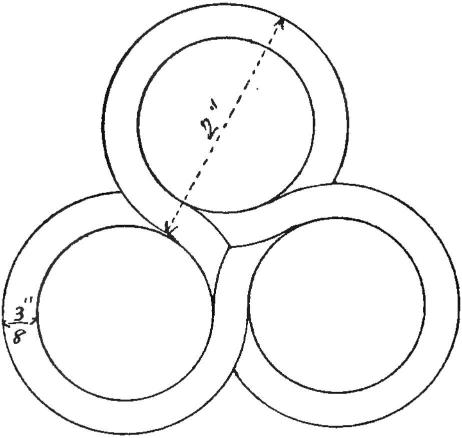


FIG. 3.

(4) In the given figure the five points of the star are situated at the angles of a regular pentagon. Draw the figure from the dimensions attached.

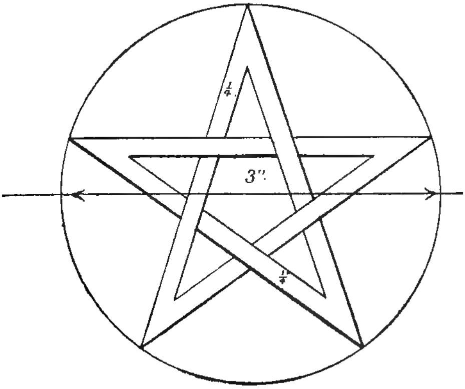


FIG. 4.

First obtain the five points of the star by construction within the circle of the required diameter. Join the alternate points, and proceed as in the given figure.

(5) To draw a foiled figure about a given regular polygon,—say a cuspidate cinquefoil about a regular pentagon.

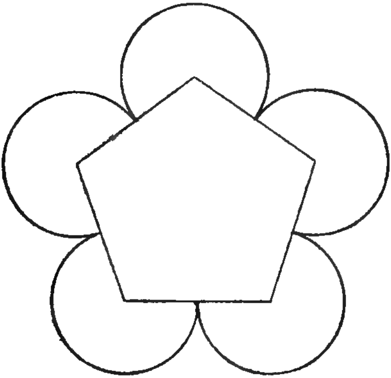


FIG. 5.

Take the corners of the pentagon as centres, and with a radius equal to half the side of the pentagon describe arcs. These will form the foiled figure required.

Note.—When two circles pass through a common point in the line joining their centres they touch at that point. The figure thus constructed will be cuspidate.

(6) Draw the three squares as shown. (Fig. 6, p. 178.)

With A and B as centres describe arcs meeting the inner square, with radius AC. The quatrefoil in the centre is drawn round the small square.

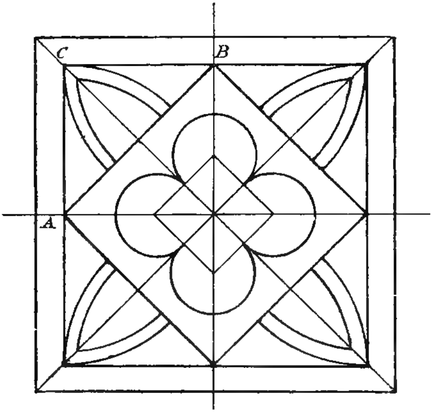


FIG. 6.

(7) Draw the geometrical pattern shown, making it half as large again as the copy.

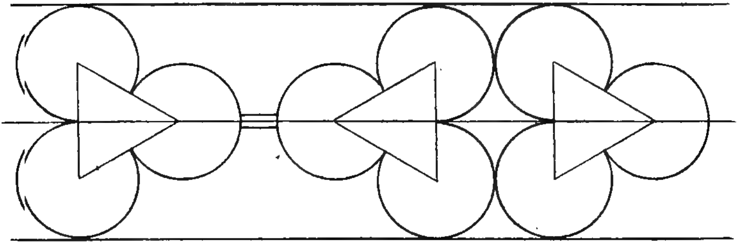


FIG. 7.

First, draw the parallel lines for the sides, also a centre line. The arcs are cuspidate trefoils about equilateral triangles.

(8) The following figure is based on the construction of regular hexagons.

First, draw seven parallel lines at equal distances; then construct the large hexagons on the bottom line. The rest of the work will be seen from the figure.

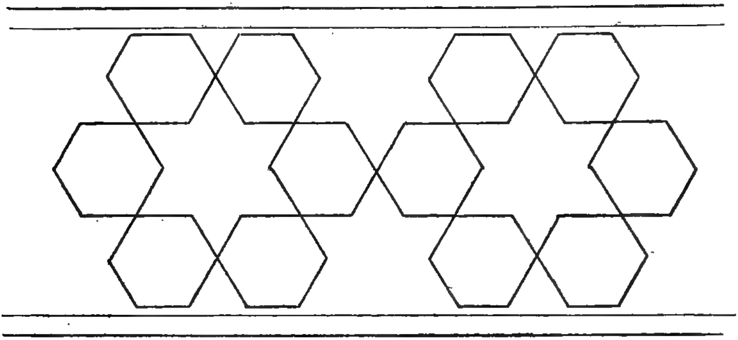


FIG. 8.

(9) **Within a given hexagon draw a hexafoil of semicircles to which the sides of the hexagon shall be tangents. On the diameter of each semicircle as a diagonal construct a square.**

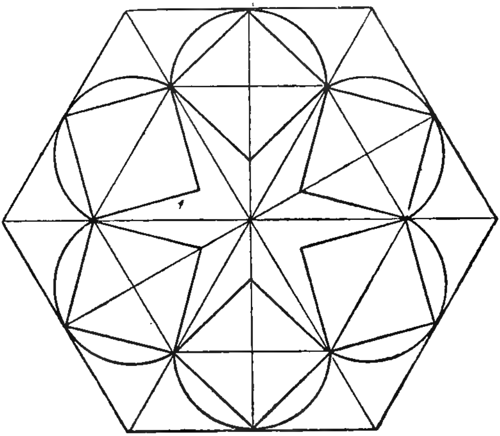


FIG. 9.

Draw lines from the corners of the hexagon to the centre, also lines from the centre bisecting the sides of the hexagon.

(10) **The following figure is to be drawn to twice the scale.**

The construction lines as shown are sufficient for the working of the figure.

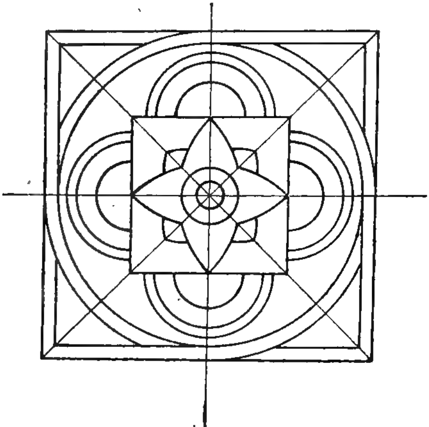
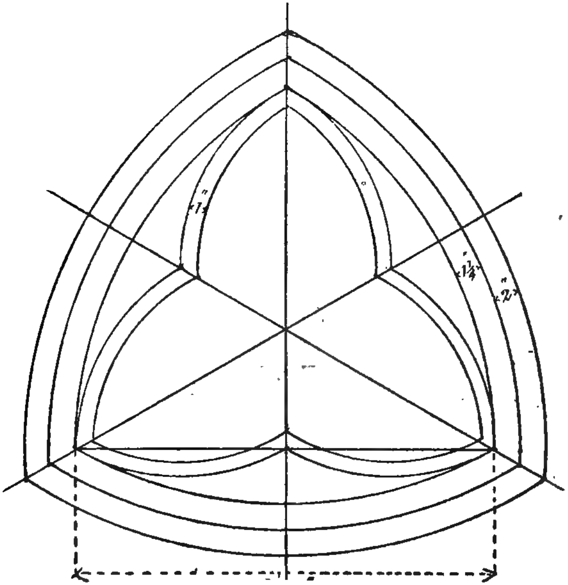


FIG. 10.

(11) The given figure represents a window of the



English decorated style. The construction is sufficiently shown and dimensions are given. Draw the window to a scale of $1\frac{1}{4}''$ to 1 foot.

(12) In a circle of $1\frac{1}{4}''$ radius draw the figure shown.

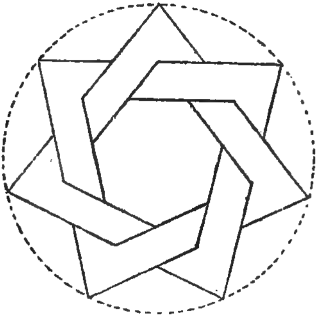


Fig. 12.

(13) Draw a figure similar to the given one, but half as large again.

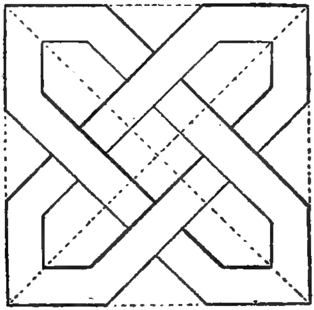


Fig. 13.

(14) Draw the given figure full size from the dimensions given in the accompanying diagram.

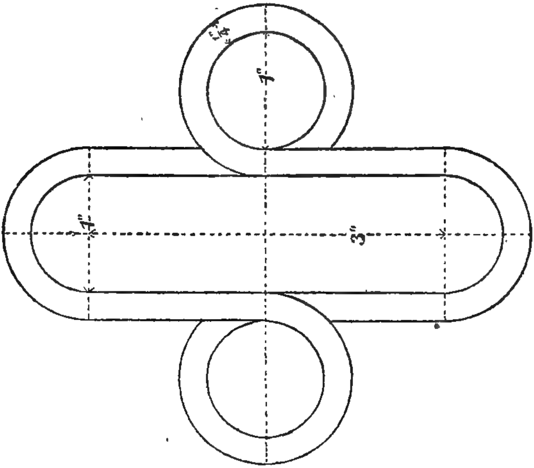


FIG. 14.

(15) Draw the given figure full size, adhering strictly to the figured dimensions.

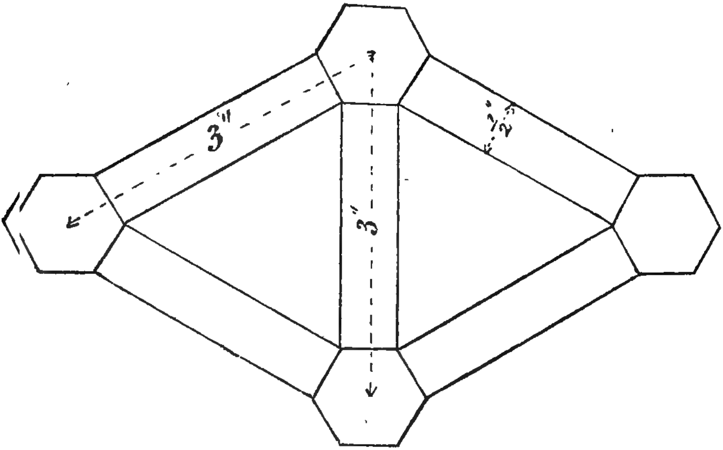


FIG. 15.

(16) Draw the given figure twice the size.

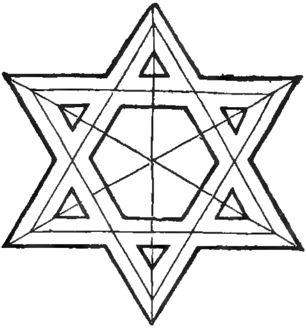


Fig. 16.

(17) Copy as accurately as you can the accompanying figure. All the curves are portions of circles.

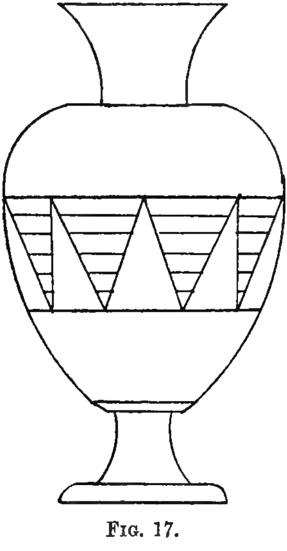


Fig. 17.

(18) Copy accurately the figure given below.

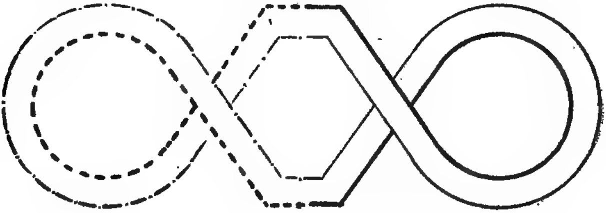


FIG. 18.

GRAPHIC ARITHMETIC.

Graphic Arithmetic is the employment of lines representing numbers. Lines are the results, and represent the required product, dividend, &c., on the same scale of units as the original lines. The results are obtained by means of geometrical proportions, instead of the ordinary process of Arithmetic.

A line may represent any number of units. For instance, a line 2″ long may represent 20 units: therefore $\frac{1}{20}$ of the line represents 1 unit, $\frac{1}{10}$ of the line 2 units, $\frac{1}{4}$ of the line 5 units, $\frac{1}{2}$ of the line 10 units, $\frac{3}{4}$ of the line 15 units; or any fraction of the unit may be shown.

(1) If a line 2″ long represents 5, what is the unit?

Divide the line into 5 equal parts. Each part thus obtained is the unit.

(2) A line 2″ long represents 5. Produce it to represent 8.

Divide the line 2″ into 5 equal parts. Produce the line and add 3 of the equal parts. The whole line represents 8, or $3+5$.

(3) Show $\frac{3}{5}$ when the unit is 2″.

Divide the unit into 5 equal parts. 3 of these parts represent $\frac{3}{5}$ of 2″ the unit, or $\frac{5}{5}-\frac{2}{5}=\frac{3}{5}$.

(4) The unit being $\frac{1}{2}$″, represent $5+2-3+1-4$.

Draw an indefinite line, and from one end A measure 5 units AB. From B add 2 units BC. From C set back 3 units CD. Add 1 unit DB. From B set back 4 units BE. AE will be found to measure 1 unit or $\frac{1}{2}$″ for $5+2-3+1-4=1$.

(5) Find $\frac{2}{3}$ when the unit is 1″.

To divide one line by another the quotient is a fourth proportional to the divisor the dividend and the unit.

(6) To determine the product of any number of lines, $a \times b \times c$, $a = 2''$, $b = 1\frac{1}{2}''$, $c = \frac{1}{2}''$. Unit 1″.

Take any line AB, and set off from A a length A1, equal to the given unit,—in this case 1″,—and erect a perpendicular 1C. Set off distances on 1C from 1, equal to the lengths of given lines, as $1a = a$, $1b = b$, &c. Draw lines from A indefinitely through these points. Along AB set off $A2 = b$, and raise a perpendicular $2x$, cutting AD in x. ∴ $2x = a \times b$. From A set off $2x$ on AB, as A3, and at 3 erect a perpen-

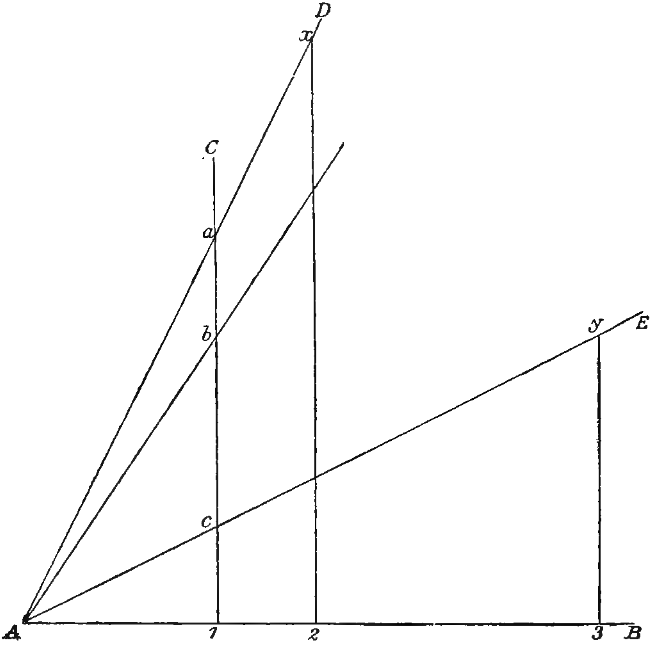


FIG. 1.

dicular meeting AE in y; $3y = 2x \times c = a \times b \times c$. The line $3y$ measured from the same scale of units as the original line is the product required. $a \times b \times c = 3y$, or $2 \times 1\frac{1}{2} \times \frac{1}{2} = 1\frac{1}{2}''$.

Note.—If lines are substituted instead of numbers, the square or any power of a line may be found by construction.

(7) Find the square of a line $1\frac{1}{2}''$ long when the unit is $1''$.

A third proportional to the unit and the line is the square of the line.

(8) Find the cube of a line $1\frac{1}{2}''$ long. Unit $1''$.

First find the square of the line as in the last problem. A third proportional to the line and the square of the line is the cube of the line.

(9) Find the fourth power of a line $1\frac{1}{2}''$ long. Unit $1''$.

Obtain the square and the cube of the line by Problems 7 and 8. A third proportional to the square and cube of the line is the fourth power of the line.

(10) Find the fifth power of a line $1\frac{1}{2}''$ long. Unit $1''$.

A third proportional to the cube and the fourth power of the line is the fifth power of the line.

Note.—The square or any power of a fraction may be found in a similar manner.

The square root of any number is the mean proportional between that number and unity.

(11) A line CD represents 9. Obtain by construction a line which will represent the square root of CD.

Divide CD into 9 equal parts, and find a mean proportional DE to CD and $\frac{1}{9}$ of CD. DE is the square root required.

(12) *Division.*—**To divide one line by another, the dividend is a fourth proportional x to the two lines and the given unit.**

(13) *Addition of Fractions.*—**Obtain the value of $\frac{1}{10}+\frac{2}{3}+\frac{1}{5}$.**

Reduced to a common denominator $=\dfrac{3+20+6}{30}$.

Draw two lines at right angles to each other, as BAC, and make AD = to the common denominator; and on the same line set off A_1, A_2, A_3, equal to the respective denominators 10, 3, and 5. Along AB set off An, An', equal to the numerators. Join the point n on AB with 1 and 3 on AC, also n' and 2. Draw lines from D parallel to $n'2$, $n3$ and $n1$ meeting AB in m, m', m_2. $\therefore \frac{1}{10}+\frac{2}{3}+\frac{1}{5}=\dfrac{Am+Am'+Am_2}{30}$.

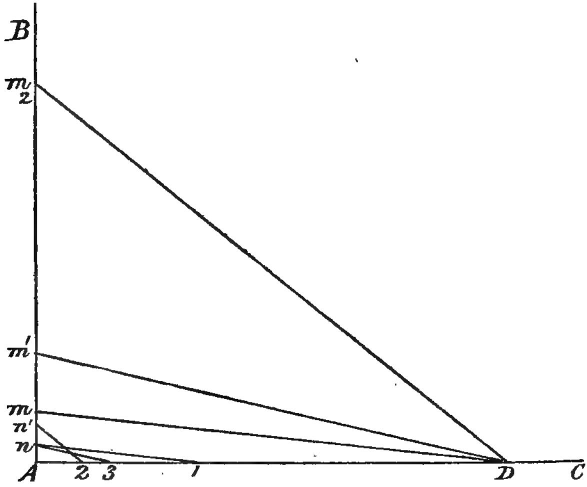


FIG. 2.

If x be the sum of the lines Am, Am', Am_2, a fourth proportional to the denominator x and the given unit will be a line representing the sum of the given fractions.

(14) If A (a line 1″ long) represents $\sqrt{7}$, what is the unit?

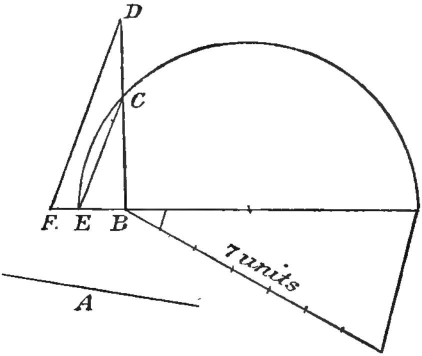


FIG. 3.

Find $\sqrt{7}$ from any scale of units, as BC. From B on BC continued set off BD equal to A. Draw a line from D parallel to CE, meeting BE continued in F. BF is the unit required.

(15) Find by construction the quantities $\frac{1}{\sqrt{3}}$, $\sqrt{\frac{5}{6}}$, the unit being a length of 2″.

Simplified are $\frac{\sqrt{3}}{3}$, $\frac{\sqrt{30}}{6}$, and, further simplified, $\frac{1}{3}$ of $\sqrt{3}$, $\frac{1}{6}$ of $\sqrt{30}$. $\frac{1}{3}$ of $\sqrt{3}$, the unit being 2″, is found by describing a circle of 2″ radius, and proceed as in Problem 131 page 70. $\frac{1}{6}$ of $\sqrt{30}$, the unit being 2″. The mean proportional between a line 10″ and $\frac{1}{30}$ of 10″ is the length of $\sqrt{\frac{5}{6}}$.

(16) Determine by construction the line—

$$x = \sqrt{a^2 - b^2 + c^2},\ a = 1\tfrac{1}{2}'',\ c = 1\tfrac{1}{4}'', \text{ and } b = \tfrac{3}{4}''.$$

Draw a and c at right angles to each other and equal to the given lengths, and on $\sqrt{a^2 + c^2}$ describe a semicircle; set off the length of b within the semicircle, from the extremity of a to point M. Draw a line from M to the extremity of c, which is x, the line required.

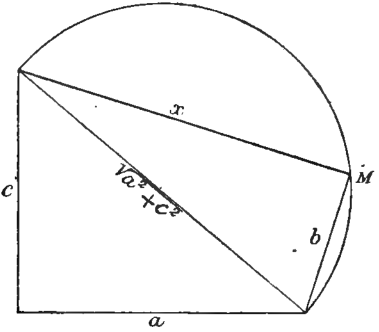


FIG. 4.

(17) Obtain by construction a line which represents $\frac{4}{5}+2\sqrt{\frac{3}{2}}$. Unit 0·5″.

$$\frac{4}{5}+2\sqrt{\tfrac{3}{2}} \text{ simplified is } \frac{4}{5}+2\frac{\sqrt{3}}{\sqrt{2}}=\frac{4}{5}+2\times\frac{\sqrt{6}}{2}=\frac{4}{5}+\sqrt{6}.$$

Find a line $\frac{4}{5}$ of ·5″. Also $\sqrt{6}$, which is a mean proportional to six times ·5″ and ·5″—*i.e.* 3″ and ·5″. A line equal to the sum of their lengths is the one required.

(18) Find by construction $x=\frac{2a}{\sqrt{3}}$, a being 2″ in length.

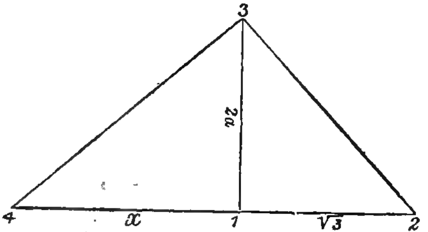


FIG. 5.
(½ Scale.)

Draw lines 1, 2 and 1, 3 at right angles to each other, 1, 2 equal to the length of $\sqrt{3}$, and 1, 3 equal to $2''$. Join points 2, 3, and from 3 draw a line 3, 4 at right angles to 2, 3, meeting 1, 2 produced in 4. The line 1, $4 = x$.

(19) Determine a line whose length shall represent $\sqrt{\frac{7}{2}}$, taking $\frac{3}{4}''$ as the unit.

Draw a line AE equal in length to the unit, and produce it to B, so that EB shall represent $3\frac{1}{2}$. A mean proportional ED between AE and EB is the square root of BE or $\sqrt{\frac{7}{2}}$.

(20) If a given line AB, $1\frac{1}{4}''$ in length, represents $\frac{7}{4}$, determine the unit.

Divide AB into 7 equal parts. 4 of these parts represent the unit.

(21) If the given line A represents the unit, what numbers do the lines B, C and D severally

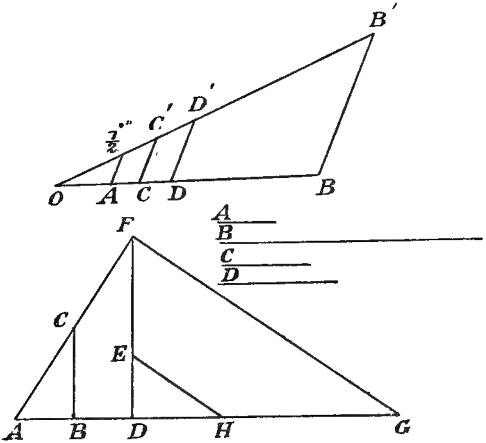


FIG. 6.

represent? Determine also a line representing $\frac{B}{C \times D}$.

Draw two lines at any angle, and mark off on one of them distances equal to A, B, C and D. From point O on the other line set out $\frac{1}{2}''$ from O, and join point A. Draw parallels to A $\frac{1}{2}''$ through C, D and B. The lengths OC′, OD′, OB′, when referred to an ordinary scale of $\frac{1}{2}''$, will show the numbers represented by the given lines.

Draw AB equal to the unit, and at B set out BC perpendicular and equal to given line C. Draw AC indefinitely. Produce AB indefinitely towards G. Measure AD equal to D, and draw DF perpendicular to meet AC in F. DF represents C × D. Make DE equal to the unit, and DG equal to B. Join FG, and draw EH parallel. $DH = \frac{B}{C \times D}$.

(22) If A represents the product of B and C, what length of line will represent the product of A and C.

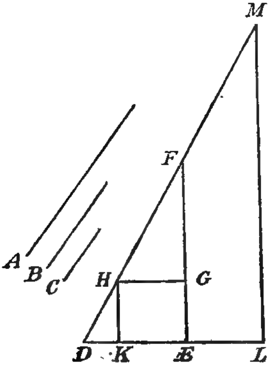


FIG. 7.

To find the unit draw DE and EF at right angles. Make DE equal to B and EF equal to A. Draw a line from D through point F. Make EG equal to C and draw GH, HK parallel to DE and EF respectively. DK is the unit. Find the product of A and C when DK is the unit. Make DL equal to A. A perpendicular to DL from L, to meet DF produced in M, gives LM, the product of A and C.

(23) If the area of an equilateral triangle of $2\frac{1}{4}''$ side is represented by $3\frac{1}{4}''$, what is the unit?

Draw a rectangle ABCD equal in area to the triangle: therefore AB × AD is the area of the figure. Find a unit so that AB × AD shall be a line $3\frac{1}{4}''$ long. At B draw BE perpendicular to AB and equal to $3\frac{1}{4}''$. A line joining A and E meets CD in F. Draw a line from F parallel to AD, meeting AB in point G. AG is the unit required.

(24) N and M are two lines. Determine $\sqrt{\frac{m}{n}}$, the unit being $0{\cdot}5''$. ($N = 1\frac{3}{4}''$ and $M = 4''$ in length.)

A fourth proportional x to the two lines N and M and the given unit is the quotient. The root of the quotient measured in units is found by Problem 131, page 70. Thus $\sqrt{\frac{m}{n}}$ is determined.

The value of x in the following equations may be determined in the same manner, 1″ being the unit.

$$x = \sqrt{\frac{2}{3}},\ x = \sqrt{\frac{10}{3}},\ x = \sqrt{\frac{\sqrt{8}}{\sqrt{3}}},\ x = \sqrt{\frac{2\sqrt{3}}{\sqrt{5}}}$$

(25) Find the angle between two lines whose equations are $x + y = 1$. $y = x + 2$.

Draw two lines at right angles to each other, as X and Y. $x + y = 1$. ∴ from a scale of units set off 1 unit to the right of O on X as m, and 1 unit above on Y as m'. Draw a line through m and m'. For the second equation set off 2 units from O to the left on X as n, and 2 units above on Y in n'. A line drawn through n, n' meets the line drawn through m, m' in A. The angle at A is the one required.

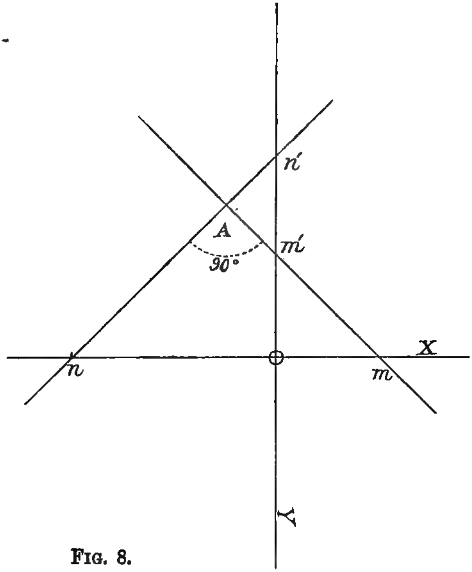


FIG. 8.

(26) Find the length of the perpendicular from point 1, – 2, on the line $x + y - 4 = 0$.

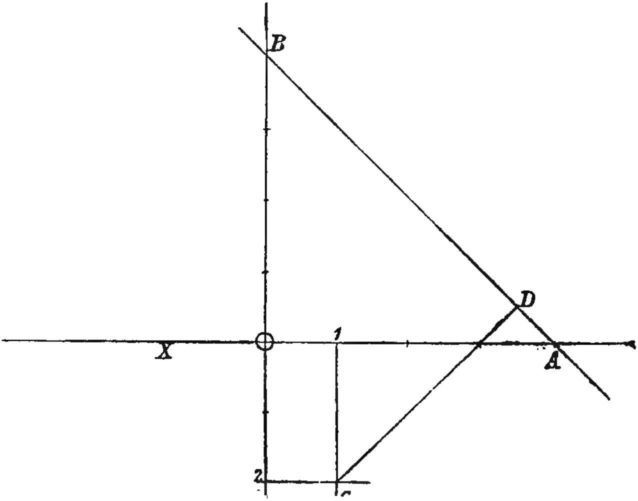


FIG. 9.

Draw two lines at right angles to each other representing X and Y, and meeting in point O.

From any scale of units set off + 4 on line X, as OA, and 4 units on Y, as OB. The line drawn through AB is $x + y - 4 = 0$.

From the same scale of units set off from O on X 1 unit, and from O on Y 2 units below. Lines drawn from 1 and 2 on X and Y, parallel to X and Y, meeting in C, give the point 1, − 2. The perpendicular CD to AB measured from the same scale of units is the length required.

(27) Determine the locus of the curve whose equation is: $(y-2)^2+(x-\sqrt{2})^2=\sqrt{2}$. Unit 1″.

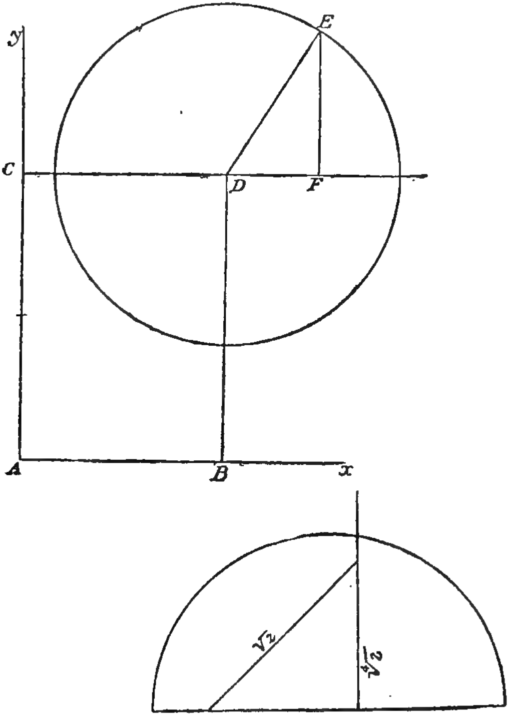


Fig. 10.
¾ths Scale.)

Assume a point A for origin, draw lines Ax, Ay at right angles, set off AB $= \sqrt{2}$, which is 1·414, and AC $= 2''$. Draw BD parallel to AC, and CD parallel to AB. From D as centre, and radius $\sqrt[4]{2}$, describe a circle ($\sqrt[4]{2}$ is found by taking a mean proportional between $\sqrt{2}''$ and $1''$).

If point E be taken in the circumference representing xy, the line EF drawn parallel to Ay, meeting CD produced in F, it may be seen that EF $= y - 2$, and DF $= x - \sqrt{2}$, and that $(\text{EF})^2 + (\text{DF})^2 = (\text{DE})^2$, or $(x - \sqrt{2})^2 + (y - 2)^2 = \sqrt{2}$.

(28) Draw the curve whose equation is: $y^2 + x^2 - 6y + 4x - 3 = 0$. Unit ·5″.

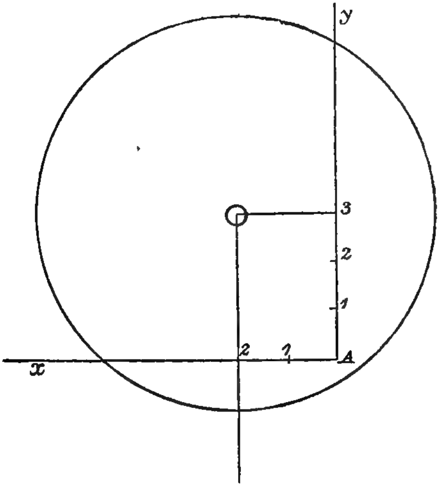


FIG. 11.

Simplified we have—

$$y^2 - 6y + 9 + x^2 + 4x + 4 = 3 + 4 + 9;$$
$$\therefore\ (y - 3)^2 + (x + 2)^2 = 16.$$

What is required is a circle having a radius equal to 4 units.

Draw two lines Ax, Ay at right angles to represent x and y, set off from A on Ax to the left 2 units, and set off from A on Ay 3 units. Draw a line from 3 parallel to Ax, and a line from 2 on Ax, parallel to Ay, meeting in O, the centre of the circle required.

The radius is equal to 4 units. Add 1 unit to line O2 below Ax. This line is the radius required.

(29) Determine the intersection of the circle $y^2+x^2=16$ with the lines $y+x=1$, $y+x=-3$.

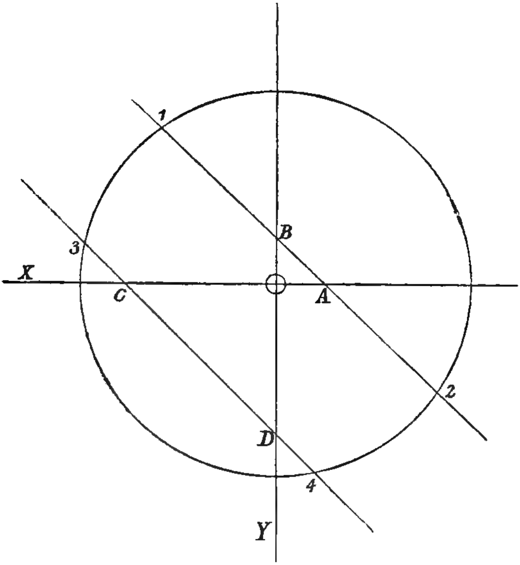


FIG. 12.

Draw two lines at right angles to each other representing X and Y, and meeting in point O.

With O as centre, and radius equal to 4 units, from any scale of units describe the circle.

From O on X and Y set off 1 unit as OB, OA. A line drawn through A and B is $y+x=1$.

From O on X and Y set off 3 units as OC, OD. A line drawn through C and D is $y+x=-3$. The lines intersect the circle in points 1, 2, 3, and 4.

(30) Find the angle between the lines $x+y\sqrt{3}=0$ and $x-y\sqrt{3}=2$.

Draw two lines at right angles to each other representing X and Y, and meeting in point O.

From any scale of units set off on X to the left of O $\sqrt{3}$, and on Y above X 1 unit as O1. Complete the parallelogram, and draw the diagonal OC. The line OC $= x+y\sqrt{3}=0$.

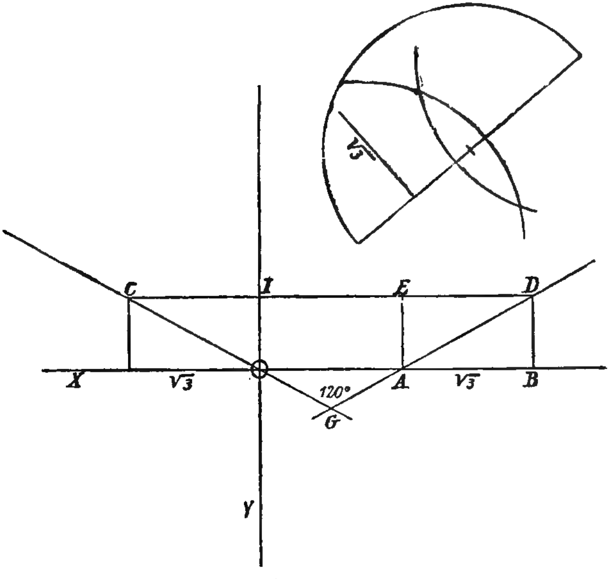


FIG. 13.

From the same scale of units set off 2 units to the right of O on X as OA, and AB $=\sqrt{3}$. BD $=1$ unit. Complete the parallelogram ABDE, and draw the diagonal AD. The line AD is $x-y\sqrt{3}=2$. The lines OC and AD intersect in G. The angle AGC is the angle required, and is one of 120°.

(31) Draw lines represented by the equation $y^2 - 4xy + 3x^2 = 0$.

The equation simplified is $(y - 3x)(y - x) = 0$.

Draw two lines at right angles to each other representing X and Y, and meeting in point O.

From any scale of units set off on Y above O 3 units as OA,

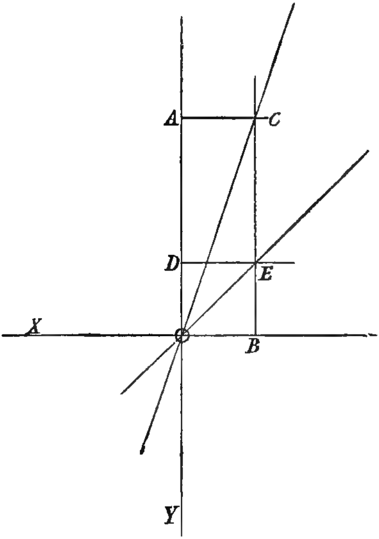


FIG. 14.

and from O on X 1 unit as OB. Complete the parallelogram OACB. The diagonal OC is $y - 3x = 0$.

From the same scale of units set off on X OB equal to 1 unit, and on Y OD equal to 1 unit. Complete the parallelogram ODEB. The diagonal OE equals $y - x = 0$.

Note.—A parabola gives the square of all quantities.

(32) Draw a curve which will give the square of all quantities from 0 to 6, taking $\frac{1}{16}''$ as the unit.

Draw any straight line *gb*, and mark upon it a starting point *o*. Set off six equal distances to the left of this point, each 1 unit in length, as *a*,*c*, *d*, *e*, *f*, *g*, and any other six equal distances to the right, as 1, 2, 3, 4, 5, *b*. At each of these points draw lines at right angles to *gb*. Set off one unit $\frac{1}{16}''$ *op* below *gb*. Join points *p* and *g*, and draw *g*G at right angles to *gp*, meeting the perpendicular through *o* in G. Join *pc*, and draw a line *c*C at right angles to *cp*. Points BDEF are found in a similar manner. Horizontal lines drawn through these points will meet the vertical lines drawn through points 1, 2, 3, &c., in points on the required curve, which is a parabola. We may apply the problem by finding the square of $2\frac{1}{2}$. Take a point along *ob* to correspond to $2\frac{1}{2}$ of the distances set off from *o* to the right. A vertical line through the point will meet the curve; its length will measure $(2\frac{1}{2})^2$ or $6\frac{1}{4}$, *i.e.*, $6\frac{1}{4}$ times the given unit $\frac{1}{16}''$.

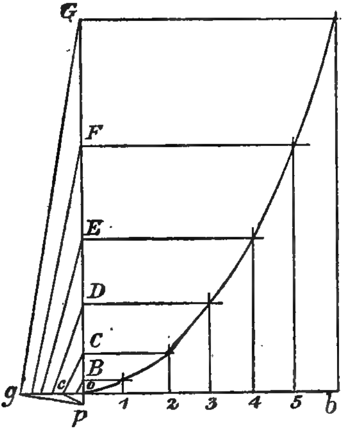


FIG. 15.

(33) Construct the curve whose equation is $y^2 = 2x - 1$. Unit 1″.

The equation simplified is $y^2 = 2(x - \frac{1}{2})$. The curve therefore is a parabola.

Draw the axis AB. The focus E will measure from A the unit 1″. Through A draw the directrix CG at right angles to AB. The vertex D is half a unit from the focus, measured on the axis. Draw EF at right angles to AB. EF equals the unit 1″. The curve is completed by Problem 195 in Practical Geometry.

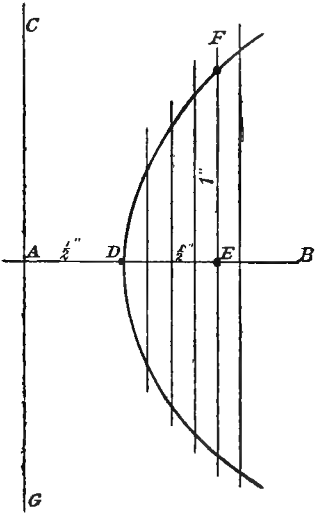


FIG. 16.

Note.—The area of any rectilineal figure may be represented by a line. To obtain this line the figure must be reduced to a triangle of equal area.

(34) To represent by a line the area of the given triangle ABC.

Take any angle of the triangle ABC as centre (in this case B), and describe an arc with radius equal to 2 units of the scale to which the given figure is drawn. Draw a tangent from A to this arc, from C draw a line parallel to AB meeting the tangent in D. The line DA represents the area of the figure measured on the same scale of units to which the original figure is drawn.

This process is called the reduction of a triangle to a given base, the base in this case being 2 units. Reduction of areas to a given base is necessary for finding the centres of gravity of plane figures.

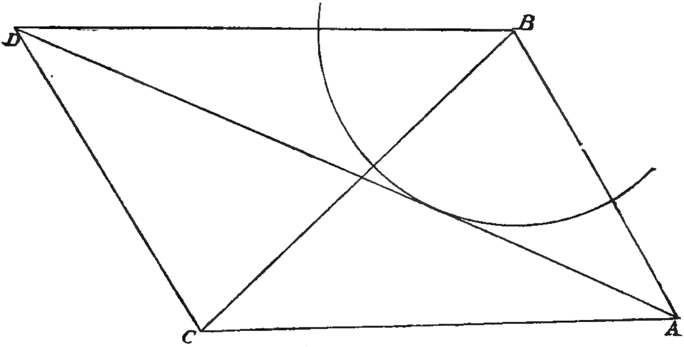


FIG. 17.

(35) To find a line to represent the area of any rectilineal figure.

First reduce the figure to a triangle of equal area, and proceed as in the last problem.

GRAPHIC STATICS.

(1) To find the resultant of two velocities along the same line.

The resultant of two or more forces acting in the same direction is the sum of those forces. If in opposite directions, the difference is the resultant.

(2) To find the result of two velocities in different directions. This is found by what is known as the parallelogram of forces.

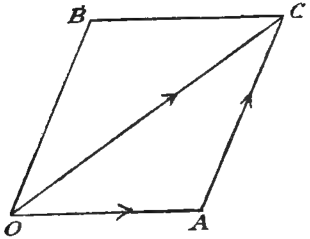


FIG. 1.

From point O draw one of the forces OA, representing the magnitude and direction of the force, and from A draw AC, representing the other force in magnitude and direction. Complete the parallelogram OACB. Join OC. OC represents the resultant.

(3) Resolve each of the given forces P and Q (P = 7 lbs., Q = 9 lbs.) along and perpendicular to

the given line AB, and write down the resultant force in each direction.

From any scale of units set off QR equal to 9 units, and from the same scale set off PS equal to 7 units. Complete the rectangles of which QR and PS are the diagonals.

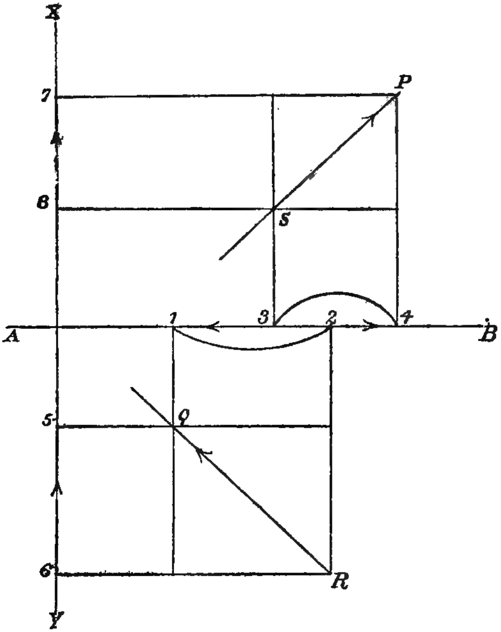


FIG. 2.

Continue two sides of the rectangles to meet AB in points 1, 2 and 3, 4, and the other two sides to meet a line XY drawn perpendicular to AB in points 5, 6 and 7, 8. The force perpendicular to AB is the sum of the lines 5, 6 and 7, 8 measured from the scale of units. The force acting along AB is the line 1, 2 forcing to the left—the line 3, 4 forcing to the right, measured from the scale of units.

(4) To find the position a weight free to move will take on a cord.

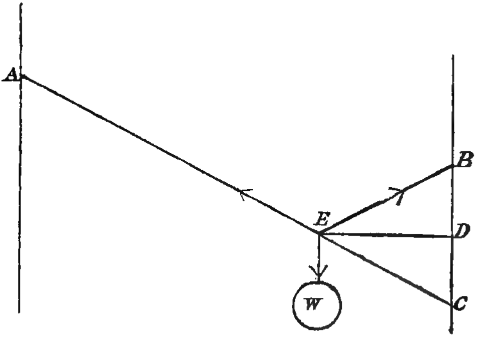


FIG. 3.

A and B are the points of suspension. Set off AC equal to the length of the cord; bisect BC in D. Draw a horizontal line from D meeting AC in E. Point E is the required position of the weight.

(5) A sphere C, of a given weight, is placed on a

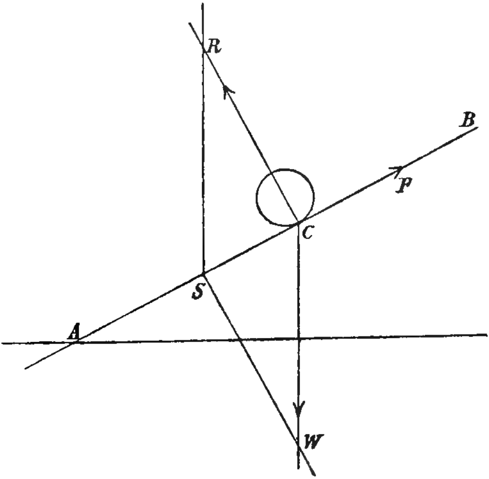


FIG. 4.

smooth inclined plane AB, and is sustained by a force F which acts along AB in the vertical plane, which is at right angles to AB. Find F.

The effect of the inclined plane is to produce a reaction R, at right angles to the plane, on the sphere. If we introduce this force, the plane we may imagine removed. Therefore draw a parallelogram CWSR, having its sides parallel to the direction of R and W. The diagonal SC is the direction and magnitude of the force F required.

(6) The direction and magnitude in lbs. of five forces, acting at one point A, are given. Determine the direction and magnitude of their resultant.

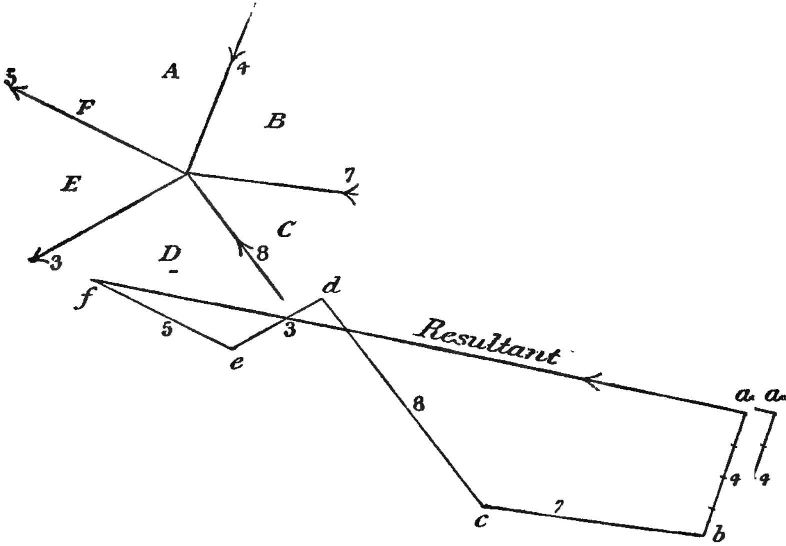


FIG. 5.

Draw a polygon of forces—*i.e.*, lines parallel to the directions of the forces, and equal in length to as many units as magnitude in lbs. The line joining the end of the first direction of forces and the end of the last is their resultant, and the direction of this force is from the starting point *a* to the finishing point *f*. The magnitude of the force is the number of units the resultant measures.

Note.—If all the forces act in parallel directions, then the polygon of forces is a straight line; and in the case of roof and bridge trusses, this polygon is spoken of as the Line of Loads.

(7) Draw six lines *ao*, *bo*, *co*, *do*, *eo*, *fo*, radiating from a point *o*, any two adjacent lines including an angle of 60°. These six lines are respectively the lines of action of forces of 80, 100, 90, 60, 120, and 50 lbs. all acting towards *o* except those along *od* and *of*, which act away from *o*. Determine and write down the magnitude and direction of the resultant of the forces.

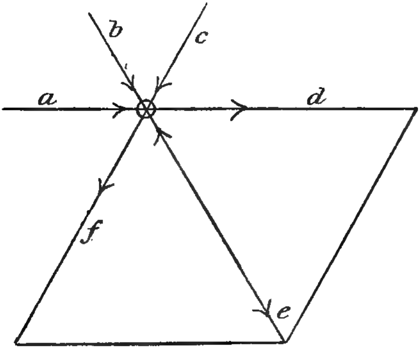


FIG. 6.

ao and *od* act in the same straight line, and are therefore equal to a single force acting from *o* towards *d* of 80 + 60 = 140 lbs.

oc and *of* are equal to 50 + 90 = 140 lbs. acting from *o* towards *f*. *ob* acts in the opposite direction to *oe*, and are equal to 120 - 100 = 20 lbs. acting from *o* towards *b*.

The resultant of the two forces is 140 lbs. acting from *o* through *e* at 60°, and forms an equilateral triangle *ofe*.

Therefore the resultant, allowing for the 20 lbs., is 120 lbs. acting from *o* to *e*.

In the drawing any unit may be taken to represent 10 lbs.

The resultant of any number of forces acting in a plane, and if their directions do not pass through one point, a funicular polygon may be employed to find the resultant. A funicular polygon is important in the subject of Statics, and is so called because it is the form a cord would assume when subjected to the forces shown.

(8) Four forces AB, BC, CD, DE act in a body. To find the resultant.

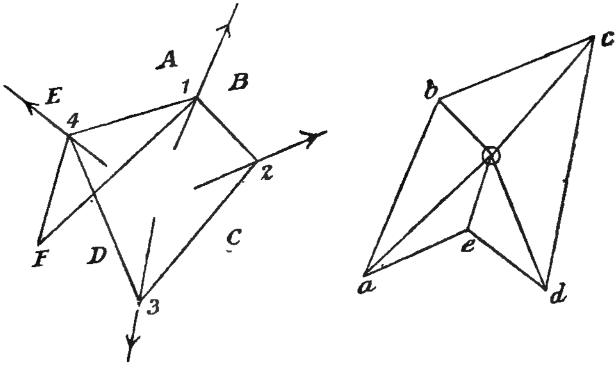


FIG. 7.

The polygon of forces will give the magnitude and the direction of the resultant, and the funicular polygon a point on its line of action.

First draw the polygon of forces, which gives the resultant *ae* in magnitude and direction. Assume any point *o* as pole, and join *oa*, *ob*, &c. Draw lines in the spaces B, &c., as lines 1, 2 2, 3 &c., parallel to *ob*, *oc*, &c. From point 4 draw 4F parallel to *oe*. Point F is on the line of action of the resultant forces. 1, 2, 3, 4 is the funicular polygon.

Note.—The process of finding a number of forces which shall have a given force for their resultant is called, Resolution of a force into its components.

(9) Given a force AB, resolve this force into two components in the directions x and y.

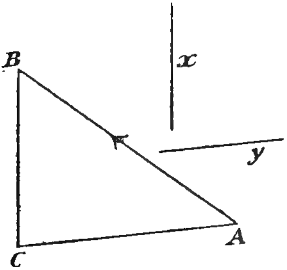


FIG. 8.

From A and B draw lines parallel to x and y meeting in C. AC and CB represent the components of AB. (See Problem 2.)

(10) A given force AB may be resolved into two components along two parallel lines of action x and y.

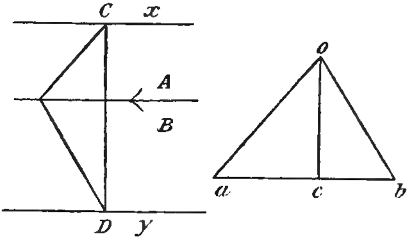


FIG. 9.

If the force AB be reversed, this force and the components of AB in the original direction will be in equilibrium. Draw the polygon of the forces, *ba* representing the original force reversed, and complete the polygon.

Draw also a funicular polygon, so that the sides in the spaces A and B are parallel to *oa* and *ob*, and meeting the lines of action in points C and D. Draw *oc* parallel to CD. Then *ac*, *cb* represent the components along x and y.

(11) A uniform rod AB, weighing 53 lbs., is pivoted at A. If a force P of 32 lbs. is applied at C, where must a parallel force of 41 lbs. be applied to maintain equilibrium?

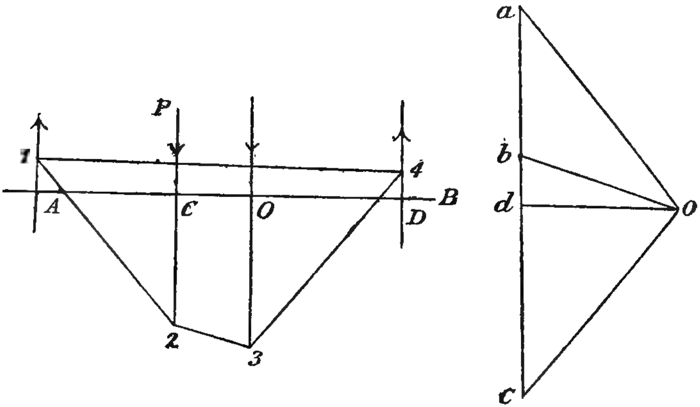


FIG. 10.

Four forces keep the bar in equilibrium—the weight of the bar acting downwards at the centre O; the given force P acting downwards at C; the reaction at the pivot A acting upwards; and 41 pounds acting upwards at an unknown point D.

Draw the polygon of forces to any scale of units—*ab* 32 lbs. or units, *bc* 53 units, *cd* 41 units.

Complete the funicular polygon 1, 2, 3, 4. Point 4 is the line of action of the weight 41 lbs. A perpendicular through point 4 meets the rod AB in point D required.

(12) Resolve the given force P, 240 lbs., along the given lines *aa*, *bb*. Write down the magnitudes of the resolved components, and indicate their directions by arrows.

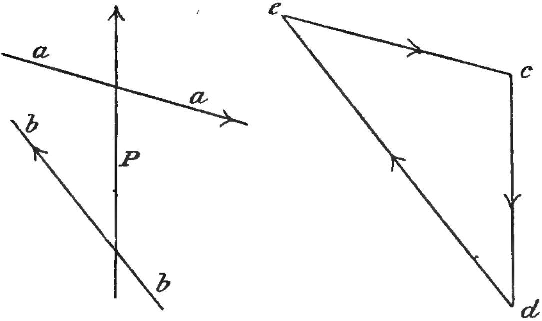


FIG. 11.

Take any scale of units and draw *cd* parallel to P, and equal to 240 units. Complete the triangle *cde*, *de* parallel to *bb*, and *ce* parallel to *aa*. Reverse the direction of the force P on *cd*, and follow the triangle round as shown. The arrow-heads show the direction of the two components. *de* and *ec* measured from the same scale of units will give the magnitudes of the forces *aa* and *bb*.

(13) A uniform beam AB, weight 44 lbs., is suspended by two strings from its extremities to the point O. A weight P of 13 pounds is hung on the beam in the given position. Determine the position of the equilibrium of the system.

Consider the weight of the beam 44 units to act at point Q, the centre of AB, and a weight of 13 at P.

If PQ be divided inversely at C, proportionally to the two loads, point C is the centre of gravity (P1 equals 44 units, Q2 equals 13 units), and point C must lie where the whole is suspended vertically under point O. Then MN perpendicular to OC is the horizontal and OC the vertical line.

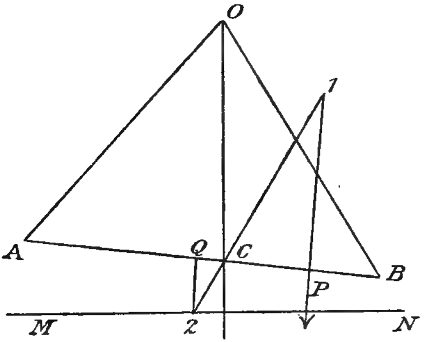


FIG. 12.

Note.—Any system of parallel forces not all acting in the same plane can be found by representing the polygon of forces and the funicular polygon in plan and elevation.

(14) To determine the reactions of a loaded beam XY on the right and left walls respectively.

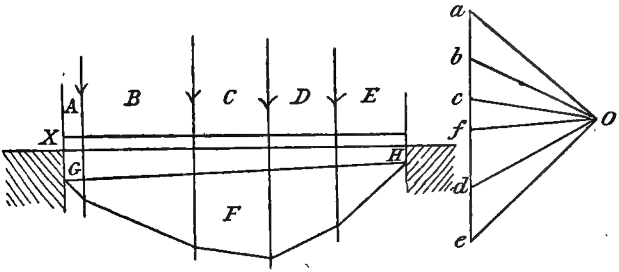


FIG. 13.

The loads are at AB, BC, &c., EF and FA the reactions. Draw the polygon of forces, also the funicular polygon in the spaces A, B, &c., parallel to *oa*, &c., and join GH. Draw *of* parallel to GH, then *ef* and *fa* are the reactions on the right and left walls.

Note.—The moment of a force about a point is equal to double the area of the triangle whose base represents the magnitude of the force, and whose height is equal to the perpendicular distance of the point from the direction of the force.

(15) To represent the moment of a force about a given point.

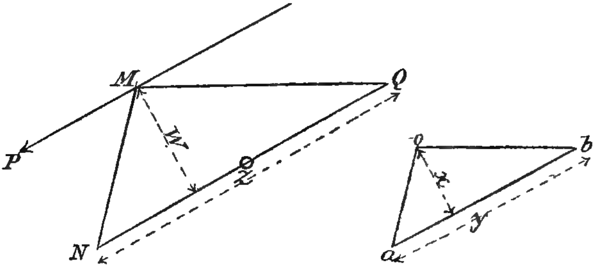


FIG. 14.

P represents the force about point O. Draw *ab* parallel to P, and representing the force to any scale of units. Let *o* be a point taken at a unit distance from *ab*; draw *oa* and *ob*. Take any point M on the line of action P, and draw MN and MQ parallel respectively to *oa* and *ob*. From O draw a line NQ parallel to P. The length of NQ represents the moment of P about O. The line NQ measured in units on the scale adopted is the moment required.

$$\therefore y \times x = z = \mathrm{P} \times w.$$

(16) To find the resultant moment about a given point P of any system of parallel forces, AB, BC, CD, DE.

Draw the polygon of forces, *ae* representing the resultant in magnitude and direction. Also draw the funicular polygon 1, 2, 3, 4, 5. The sides 4, 5 and 1, 5 intersect in point 5; a point in the line of action of the resultant ae. A line drawn through

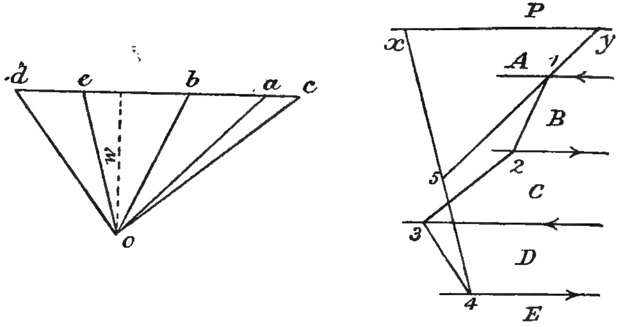


FIG. 15.

P parallel to ae meeting lines 1, 5 and 4, 5 in points x and y. Then $xy \times w$ is the required moment.

In practice O should be taken, so that the product $w \times xy$ may be easily determined. Some multiple of 5 will be found the most convenient length of the polar distance. If O be taken at unit distance from ae then $w \times xy = xy$, and the required moment will be found by measuring xy.

Note.—The moments of a system of forces can be represented by a series of rectangles; and if reduced to equivalent rectangles all of which have equal bases, a scale can be constructed from which the heights of the rectangles read off, give the value of the several moments according to the scale of units adopted.

(17) Reduction of moments to a common base.

In the figure a^1 P^1, a^2 P^2 . . . . represent the magnitude, direction, and position of forces whose moments about any point O in their plane are to be reduced to a common base. Suppose that the common base to which the moments are to be reduced is H. Draw any line XY through O, and from a^1, a^2, &c., draw lines a^1b^1, a^2b^2, &c., parallel to XY, and equal to the given base H. Join b^1P^1, b^2P^2, &c. Through O draw Oc^1, Oc^2, &c., parallel to b^1P^1, b^2P^2, &c., and meeting a^1P^1, b^2P^2, &c., produced in c^1, c^2, &c. From c^1, c^2, &c., drop perpendiculars

c^1d^1, c^2d^2, &c., on the line XY. These perpendiculars, $c^1d^1 = m^1$, $c^2d^2 = m^2$, &c., are the required heights of the rectangles, having H as the base.

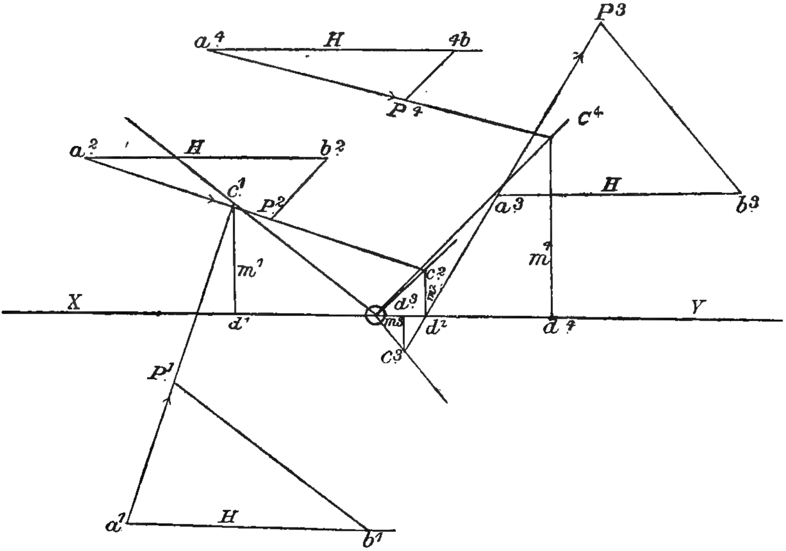


FIG. 16.

The scale of force is 100 lbs. to 1″.

The linear scale is 80 feet to 1″.

The scale of moments must be so drawn that y units on the scale of force equals $y \times 100$ units on the scale of moments; thus on the latter scale 1″ represents 1000 foot lbs.

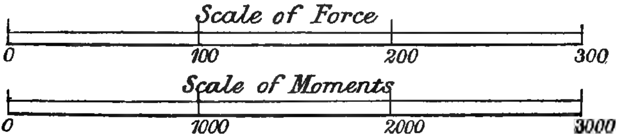


FIG. 17.

(18) To find the resultant moment about a given point P of any system of forces AB, BC, CD, DE.

Draw the polygon of forces, *ae* representing the resultant in magnitude and direction. Also draw the funicular polygon 1, 2, 3, 4, 5. The sides 4, 5 and 1, 5 intersect in point 5; a

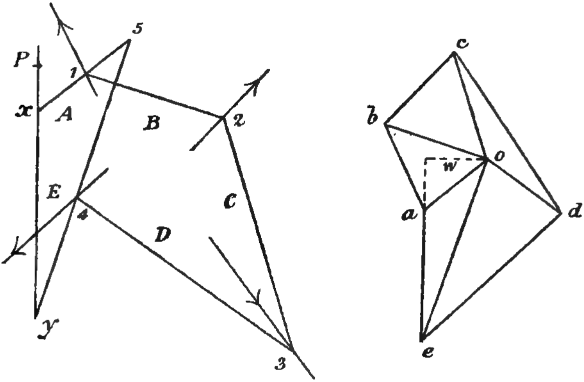


FIG. 18.

point in the line of action of the resultant *ae*. A line drawn through P parallel to *ae*, meeting lines 1, 5 and 4, 5 in points *x* and *y*. Then *xy* × *w* is the required moment.

A couple consists of two concurrent parallel forces which act in the same direction, or two parallel forces which act in opposite directions, which are said to be non-concurrent. If the forces forming a couple were in the same straight line they would be in equilibrium.

The two forces applied by the thumb and fingers to the handle of a common tap form a couple.

The twist applied to a screw-driver without pressure is a couple. A couple tends to cause rotation; and when in the direction of the hands of a watch, the couple is called negative, when in the opposite direction it is called positive.

The arm of a couple is the perpendicular distance between the lines of action of the forces.

The moment of a couple is equal to one of the forces multiplied by the arm of the couple.

Couples may be solved graphically by the funicular polygon, the polygon of forces, and Graphic Arithmetic.

(19) Weights are suspended from the given points along a weightless rod, as AB, BC, CD, DE, EF, FG. To determine the point about which the rod will balance.

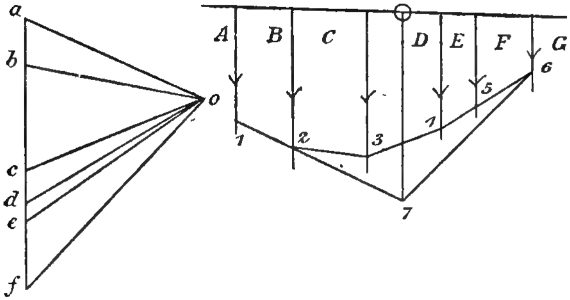


FIG. 19.

Draw the polygon of forces, also the funicular polygon 1, 2, 3, 4, 5, 6, 7. The sides 1, 7 and 6, 7 intersect in point 7, a point in the line of action of the resultant. A line drawn from 7 parallel to the line of loads meets the rod in point O, about which the loaded rod will balance.

(20) Let the vertices of a string or chain be denoted by the numbers 1, 2, 3, 4, 5 and 6, and let the forces P_2, &c., act at the vertices. The tension on the portion of the string 1, 2 being known, to find the tension on the remaining parts.

Take a point O, and draw from it a line A parallel to the string (1, 2) and proportional to the tension T12 (that is, draw from O a line parallel to 1, 2, and 12 units in length). From the end of A draw the line B parallel to P_2, and a line C from O parallel to the portion of the string 2, 3, meeting the line B. The line C measured in units is the tension on the portion of the string 2, 3. By completing the polygon of forces, the tension on the successive portions of the string may be found.

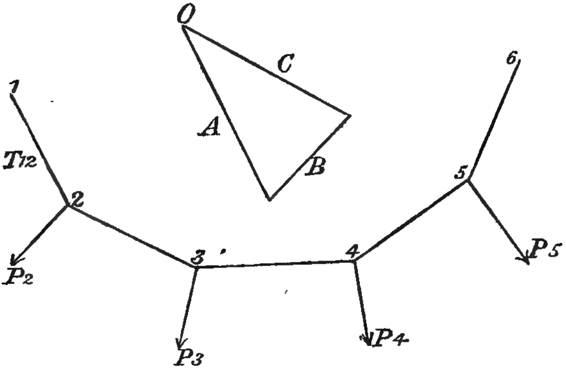


FIG. 20.

(21) The following skeleton diagram shows a wharf crane, carrying a weight W, 6 tons. Show by

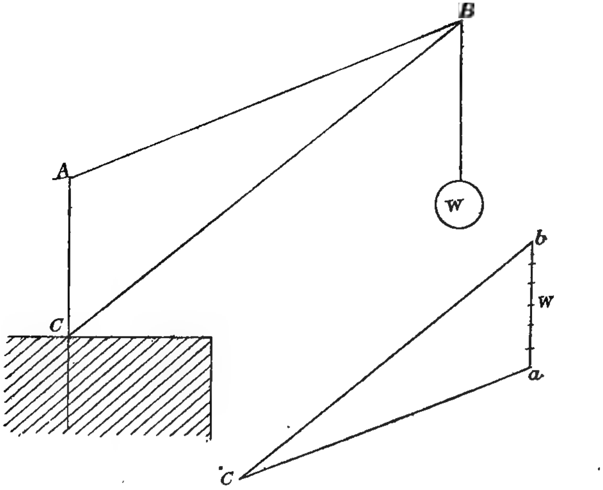


FIG. 21.

construction the different stresses on the tension rod AB, and the jib BC.

At the jib-head B three forces meet and are in equilibrium—the downward pull of the weight, the resistance of the tension rod, and the thrust of the jib. Therefore draw a line *ab* 6 units in length parallel to the downward pull of the weight. The length of the other sides of the triangle *ab*, *bc*, will represent the tension upon the tie-rod and the compression upon the jib. (The sides of the triangle are drawn parallel to AB and CB.)

(22) In the given figure BC represents the position of a pole and AC a tension guy. Show by construction the method of ascertaining the strains upon the pole and the guy, W being 6 tons.

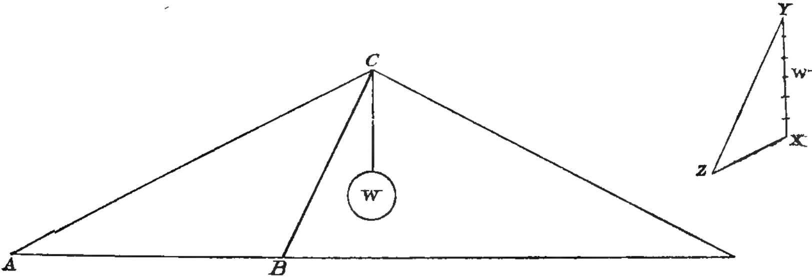


FIG. 22.

The tension rod in this case is called a "guy," and is generally made of rope. The holdfast of the guy is a strong picket driven into the ground, and the pole is supported by a foot plate, placed upon timber at B.

Draw the vertical line XY 6 units in length to represent W. Draw YZ parallel to BC, the sheer leg, meeting a line drawn from X parallel to the guy AC. The length of XZ measured to the same scale of units gives the tension on the guy AC, and YZ measured in units the thrust on the sheer leg.

(23) If a load of 2 tons acts on the ridge of a roof truss, to find the stresses on its members and to determine which are in compression and tension.

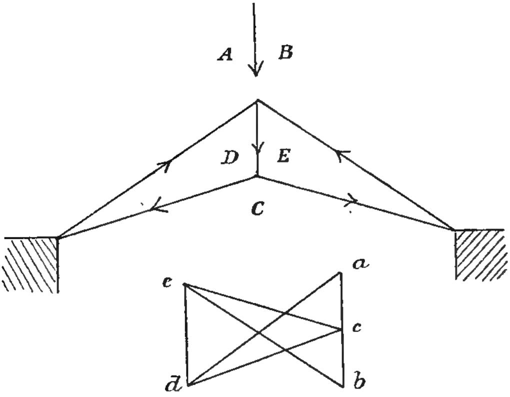


Fig. 23.

Draw *ab* 2 units in length to represent 2 tons. The roof is evenly loaded, the reactions are equal. Bisect *ab* in *c*; *bc*, *ca* represent the reactions BC and CA. Draw *ce* parallel to CE, *be* parallel to BE. *bce* is the triangle of forces for half the truss. *be* and *ce* measured from the same scale of units will give the magnitude of the stresses. The triangle *acd* in the same manner will give the other half the truss. Notice carefully the direction of the lines in the triangles of forces—*be* upwards ∴ BE in compression; *ec* downwards ∴ CE in tension; and so on clockwise round the truss.

(24) Equal weights WW, each 500 lbs., are suspended from the points *a* and *b* of the given roof truss. The truss is otherwise unloaded. Determine by construction and write down the stresses in the several bars.

The weight distributed on each wall is 500 lbs. plus the weight of the truss. From the question the weight of the truss need not be considered. The whole structure is kept in equilibrium by four exterior forces: the reactions on the wall M and Q, and the weights W_1 and W_2.

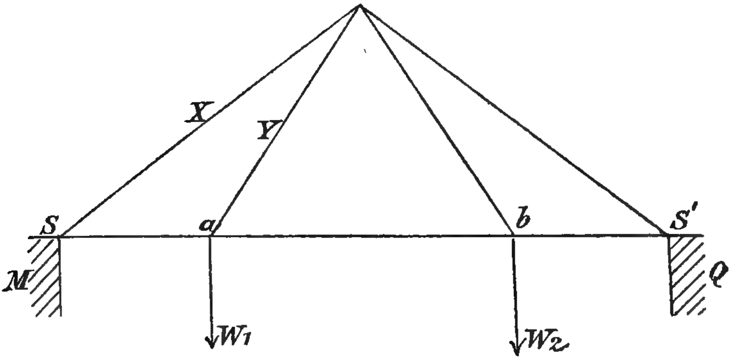


FIG. 24.

These four exterior forces are balanced by the interior forces of compression and tension, the amounts of which can be found graphically.

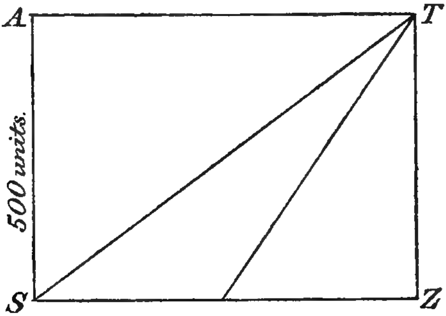


FIG. 25.

If one force be known, and the lines of action of another two, and all these acting at a point in one plane, then the nature and amounts of these forces may be found by the triangle of forces.

Therefore, draw a vertical line AS, to represent the vertical thrust on the wall,—in this case 500 units. A line ST drawn from S parallel to the rafter X, meeting a line AT drawn at right angles to AS, measured in units, is the oblique thrust upon the rafter X. A line drawn from T parallel to the tie-rod Y, meeting the horizontal line drawn through S, measured in units, represents the oblique tension on the tie-rod Y. Complete the parallelogram ZTAS. SZ, measured in units, represents the horizontal tension on the parts a S,bS′ of the tie-beam SS′.

(25) To find the centre of gravity of a triangle ABC.

Bisect AC in E, join BE; the centre of gravity lies in the line BE. Bisect BC in D, join AD; the centre of gravity lies in the line AD. The lines AD, BE intersect in G, the centre of gravity of the triangle. EG measures one third of BE, DG one third of AD.

(26) To find the centre of gravity of any quadrilateral ABCD.

Draw the diagonal BD, and by the last problem find the centres of gravity 1 and 2 of the triangles ABD and BCD. Join 1 and 2; the centre of gravity of the quadrilateral lies in this line. Draw the diagonal AC, and find the centres of gravity 3 and 4 of the triangles ABC and ACD; join points 3 and 4. The lines 1, 2 and 3, 4 intersect in point G, the centre of gravity required.

Note.—The centre of gravity of a uniform straight line is its middle point.

(27) To find the centre of gravity of a broken line AB, BC, CD, DE.

The weight of the different parts AB, BC, &c., act through the middle points of the lines and in proportion to their lengths. Draw the polygon of forces and take any pole *o*. *ae* is the direction and half the magnitude of the resultant. Draw the funicular polygon 1, 2, 3, 4, 5, point 5 being on the line of action of the resultant. Draw 5G parallel to *ae*. By placing the polygon of forces in another position, say at right angles to the first, we may obtain a second funicular polygon. This polygon is not shown in the figure, to save confusion; but the direction is shown, which passes through the point of action of the second funicular polygon. The resultants intersect in G, the centre of gravity.

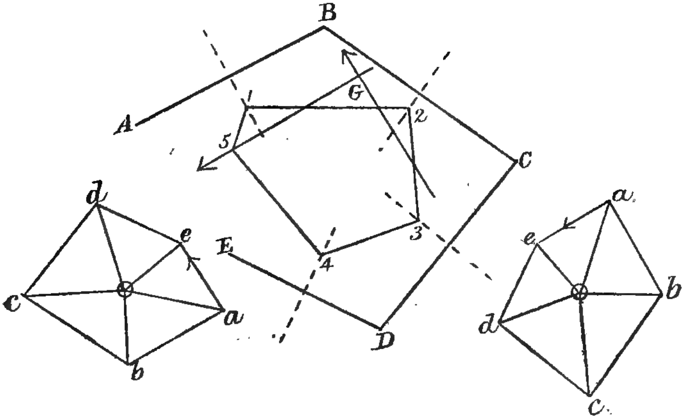


FIG. 26.

(28) To find the centre of gravity of a broken line AB, BC, CD, the lines forming a part of a regular polygon.

If AD be joined and bisected by EF at right angles, EF is an axis of symmetry, and will contain G, the centre of gravity. Proceed as in the last problem. Only one funicular polygon will be required.

(29) To find the centre of gravity of an arc ABC.

If AC be joined and bisected by OB at right angles, OB is an axis of symmetry, and will contain the centre of gravity.

Draw a tangent BD at B, equal in length to the arc AB. Draw a line from D to the centre O of the arc. Draw a line through

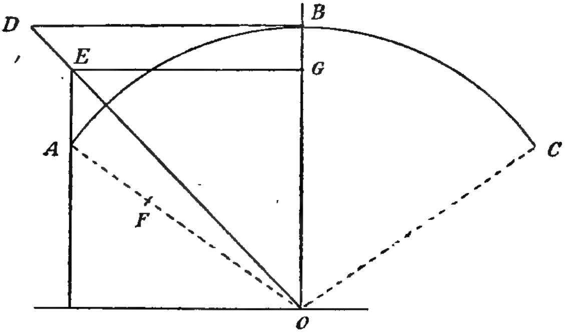


FIG. 27.

A parallel to OB, meeting DO in point E. A line from E drawn parallel to AC meets OB in point G, the centre of gravity.

(30) To find the centre of gravity of a sector AOC.

If we consider the sector AOC (see last problem) consisting of a number of triangles, the line AO may be considered as one, —its centre of gravity being F, $\frac{2}{3}$ of AO, measured from O. An arc described with O as centre, and radius OF, contains all the centres of gravity of all the triangles in the sector. The centre of gravity G of this arc is the centre of gravity of the sector AOC.

(31) Determine by construction the different stresses in the given roof truss, the total load on the truss being assumed as 18,000 lbs.

The load may be considered as concentrated at *a*, *c*, and *b*.

It is best to work from the reaction of the support—which is equal to the weight upon it, and is half the vertical loads acting at *c*, *b*, *c*′, or 9000 lbs.

To find the strain on the lower part of the principal rafter and tie-rod. From a draw a vertical line, and from any scale of units set off ah equal to the reaction of the support—viz. 9000 lbs. Draw hi parallel to ac, meeting ae in i; then hi represents the thrust in ac, and ai the tensile strain in ae, measured from the same scale of units.

To find the strains in members round point c. Draw a vertical line and mark off $i'b'$ equal to the load carried at c (6000 lbs.) Draw $h'i'$ parallel to ac and equal to ai. Draw $b'f'$ parallel to bc and $f'h'$ parallel to ec. Then $b'i'$ equals thrust in ac, $i'b'$ equals 6000 lbs., $b'f'$ equals thrust in bc, and $h'f'$ equals thrust in ec.

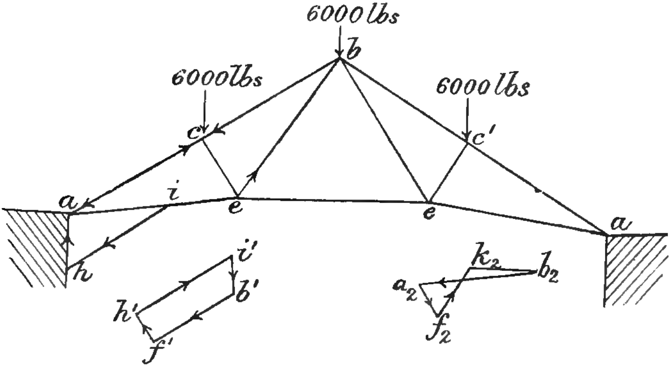


FIG. 28.

To find the strains in the members round joint e. Draw b_2a_2 parallel to ea and equal to ai; draw a_2f_2 parallel to ec and equal to $f'h'$. These are the known strains. Then draw f_2k_2 parallel to eb and k_2b_2 parallel to ee; f_2k_2 will be the tension in the bar eb and k_2b_2 the tension in ee.

(32) Find by construction the thrusts on the rafters and struts, also the strains on the tie-rod and the King and Queen rods of the given truss.

lk is the King rod, ef is a Queen rod; af and ek are struts;

ae is a bay formed by the intersection of the struts and rafters. There are six bays in the diagram.

$$\frac{\text{Total load on Truss}}{\text{Number of Bays}} = \text{W, the load carried by each bay.}$$

To find the thrust in *ma* and tension in *mf*. Draw CA parallel to reaction at *m*, and equal to it from any scale of units. Draw AB parallel to *am* and BC parallel to *mf*. Then AB equals the thrust in *am*, and BC the tensile strain in *mf*.

To find the strains in members round the joint at *a*. We know the thrust in *am* and the load *a*. Draw these known forces DE parallel to *ma* and equal to BA, also EF equals the load at *a* acting vertically. Draw lines parallel to *ea* and *af*, as FG and GD. These give the thrusts in *ea* and *af*.

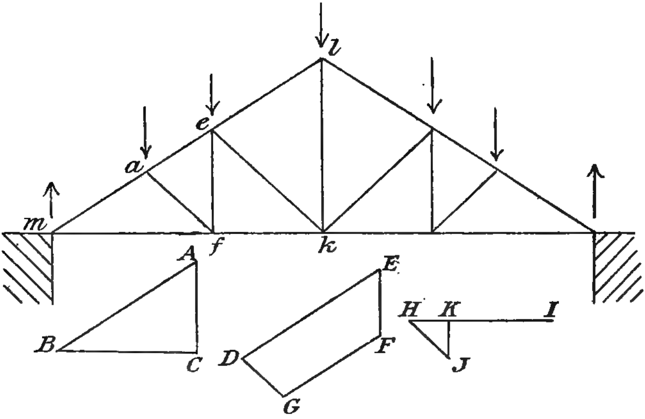


FIG. 29.

To find the strains in members round joint *f*. The strains in *fm* and *fa* are known. Draw these as HI equals BC and HJ equals DG. Then draw JK parallel to *fe* to meet HI in K. Then JK equals strain in *fe* and KI strain in *fk*.

In the same way we deal with the other joints. We know from the preceding diagrams all the forces acting at the joints except two. These can easily be found as their directions are known.

To illustrate this, take the members round the joint at *e*. We know the strain in *fe*, in *ae*, and the load acting downwards at *e*. We require the strains in *el* and *ek*. Form a portion of a polygon with the known forces taken in order round the joint, then the closing lines of the polygon (parallel to the other members *el* and *ek*) will be the strains in those members.

EXAMPLES.

(1) What is Graphic Arithmetic?

(2) Divide the circumference of a circle, by means of the compasses only, into five equal parts.

(3) If a line AB 3·4″ long represents 17, what does a line CD 2″ long represent? State the unit.

(4) Find the product of lines $A \times B \times C \times D \times E$. $A = 1''$, $B = \frac{3}{4}''$, $C = 1\frac{1}{4}''$, $D = 2''$, $E = \frac{1}{2}''$.

(5) Two lines $AB = 2\frac{1}{2}''$ and $CD = 1\frac{3}{4}''$. Divide AB by CD, and write down the length of the quotient.

(6) $\frac{AB}{CD} \times EF$. $AB = 3''$, $CD = 1\frac{3}{4}''$, $EF = 1\frac{1}{4}''$.

(7) Obtain the value of $\frac{1}{7} + \frac{1}{9} + \frac{2}{21} + \frac{1}{18}$.

(8) Obtain the value of $\frac{1}{3} + \frac{1}{4} + 1\frac{1}{5} + \frac{1}{6}$.

(9) Determine the roots $\sqrt{3}$, $\sqrt{4}$, $\sqrt{7}$, $\sqrt{9}$, the unit being 1″.

(10) Determine the roots $\sqrt{5}$, $\sqrt{6}$, $\sqrt{8}$, with the pencil compasses only, the unit being 1″.

(11) If a line represents 11, find the square root by construction.

(12) If XY represents 9, find the square root of XY by construction.

(13) Find by construction the quantities $\frac{1}{\sqrt{2}}$, $\sqrt{\frac{3}{5}}$, the unit being $2\frac{1}{2}''$.

(14) Determine by construction the line—

$$x = \sqrt{a^2 \times b^2 - c^2}. \qquad a = 2\tfrac{1}{2}'', \ b = 1\tfrac{1}{4}'', \ c = 2''.$$

(15) Find by construction $x = \frac{3a}{\sqrt{2}}$, a being 2″ in length.

(16) Find by construction $x = \frac{2a}{2}$, a being 2″ in length.

(17) Obtain by construction the following lines, the unit being ·5″ :—

$$\frac{4}{5} + 2. \qquad \frac{4}{5} + \sqrt{\frac{3}{2}}. \qquad \frac{1}{3} + 1 \sqrt{\frac{2}{3}}.$$

(18) Draw a triangle having sides 3″, 2″, $2\frac{3}{4}$″. Determine a line representing the area of the triangle.

(19) Find the angle between two lines whose equations are $x - y = 1$, $y = x - 2$.

(20) Find a point 2 – 3, and from the point draw a line to meet $x + y - 3 = 0$, the angle between the lines being 30°.

(21) If a line 1″ in length represents $\sqrt{17}$, what is the unit?

(22) Find the angle between the lines $x + y = 0$, and $x - y = 2$.

(23) Find the angle between the lines $x + y\sqrt{2} = 1$, and $x - y \sqrt{2} = 0$.

(24) Determine the lines $y + x = 2$. $y + x = -2$. $y + x = 1$. $y + x = -3$.

(25) What is meant by the moment of a force about a point?

(26) Three forces acting at a point are in equilibrium; two of the forces are 7 lbs. and 5 lbs. respectively, and the angle between these forces is a right angle; find the other force?

(27) Two parallel forces of 7 and 10 lbs. act at a distance of 1 foot. Find the resultant, (*a*) when the forces are in the same direction; (*b*) when they act in different directions.

(28) If equal parallel forces all in the same direction act at four of the angular points of a regular pentagon, find a single equivalent force to them.

(29) Find the centre of gravity of a rhomboid, 3″ × $1\frac{1}{4}$″, and included angle 60°.

(30) Four forces act away from a point of 12, 9, 17 and 10 units respectively. Find the force that will produce equilibrium.

(31) Four equal weightless rods are hinged together to form a rhombus ABCD, and the hinges A and C are connected by a string. If the rhombus be suspended from A, and equal weights of 1 cwt. each be suspended from B and D, find the tension on the string.

(32) The sides of a triangle are 2″, 3″ and 4″. Find the area in square inches.

(33) A uniform beam AB, weight 100 lbs., is supported by two strings AC, BD, the latter being vertical. It is maintained in this position by a horizontal force P applied at B. Find the value of P in lbs.

(34) Find the centre of gravity of an arc of a circle.

(35) If four forces in one plane be in equilibrium, and the lines of action of all be given, but the magnitude of only one, show how the magnitudes of the other three may generally be determined.

(36) Find the centre of gravity of a quadrilateral figure which has two sides parallel.

(37) Enunciate the Polygon of Forces.

(38) Find the centre of gravity of a broken line ABCDE.

(39) Determine the line of action, and write down the magnitude of the resultant of five given parallel forces acting in one plane.

(40) A line 3″ long represents the sum of the areas of a pentagon, square, and equilateral triangle of 1″ side. Determine the length of the unit.

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